The Transformation of Hydrofracked Reservoirs to Thermal Energy Production*

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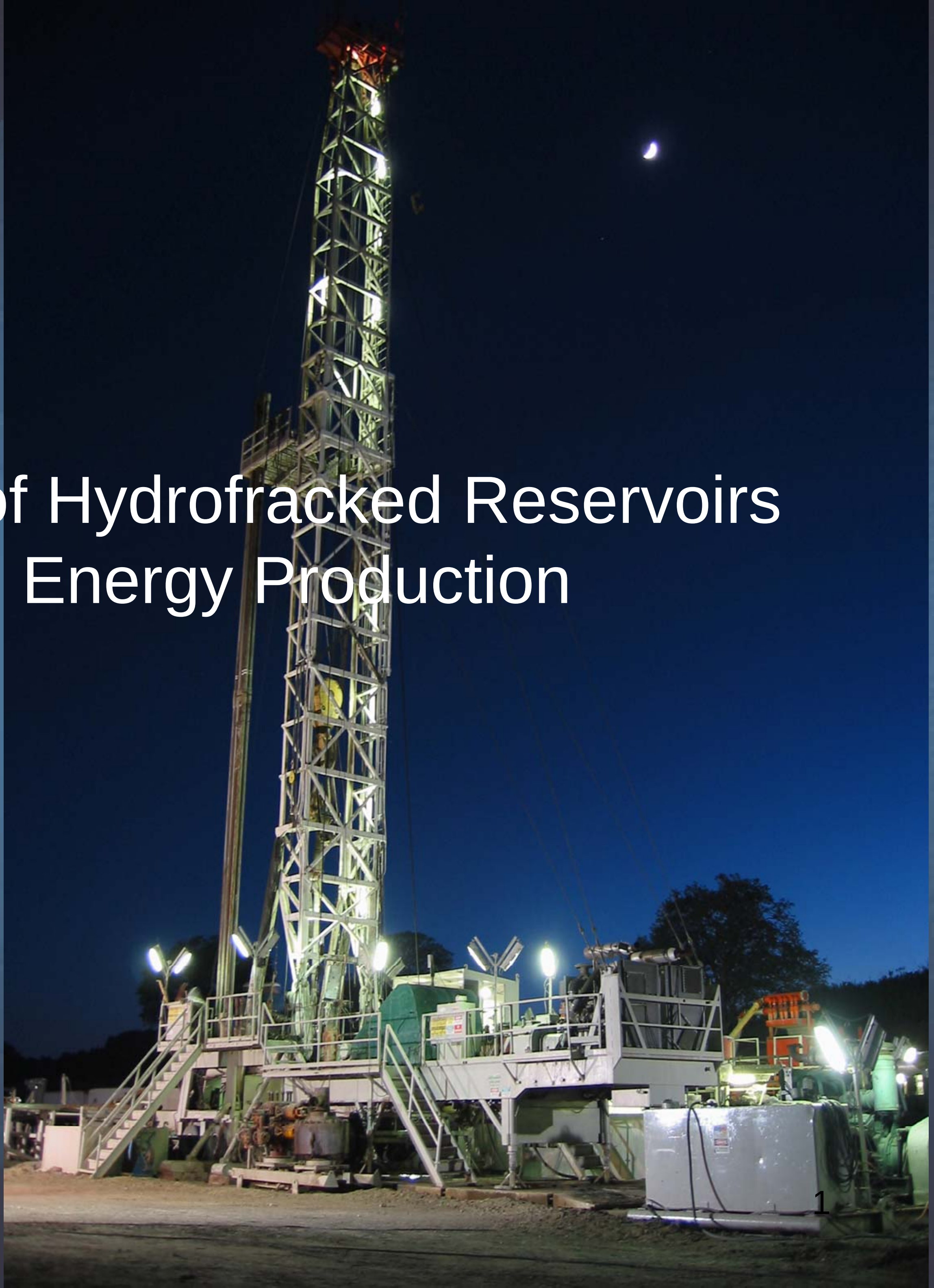
Abstract

Organic rich, low permeability formations in many locations throughout North America contain significant volumes of natural gas, but not until the early 1990s was it deemed practical to extract this gas resource in economic quantities. Hydrofracturing, pioneered by Mitchell Energy Company on the Barnett Shale in East Texas, demonstrated the technical feasibility of developing these tight formations along with horizontal drilling techniques that resulted in high-volume yields from wells that previously did not flow at rates sufficient to recover the initial investment of drilling. Development of these tight formations using hydrofracturing and horizontal drilling has transformed the North American natural gas industry, and has added, by some estimates, at least another 200 years of reserves at the present rate of natural gas consumption.

Individual wells, however, in most circumstances, do not have an extended economic lifetime as yields from these fracture-stimulated wells generally decline quickly and new wells must be drilled and fractured. The substantial investment in well design, installation and reservoir stimulation should not be abandoned, however, as many of these wells can be converted into thermal mining wells, yielding geothermal energy on a sustainable basis for as long as the well casing and well integrity can be maintained. Parametric analysis of typical wells indicates that each well cluster contains and can yield from ten million to eighty million barrels of oil equivalent in extractable thermal energy, and there are several thousand promising candidate wells for this procedure. As important as is demonstrating the extractable thermal energy from these wells is that these thermal yields are renewable over reasonable time frames, making the potential energy production from these wells in geothermal energy many times greater than the BTU content of the natural gas originally produced from the wells.

The Transformation of Hydrofracked Reservoirs to Geothermal Energy Production



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April 24th, 2012 AAPG Long Beach, CA

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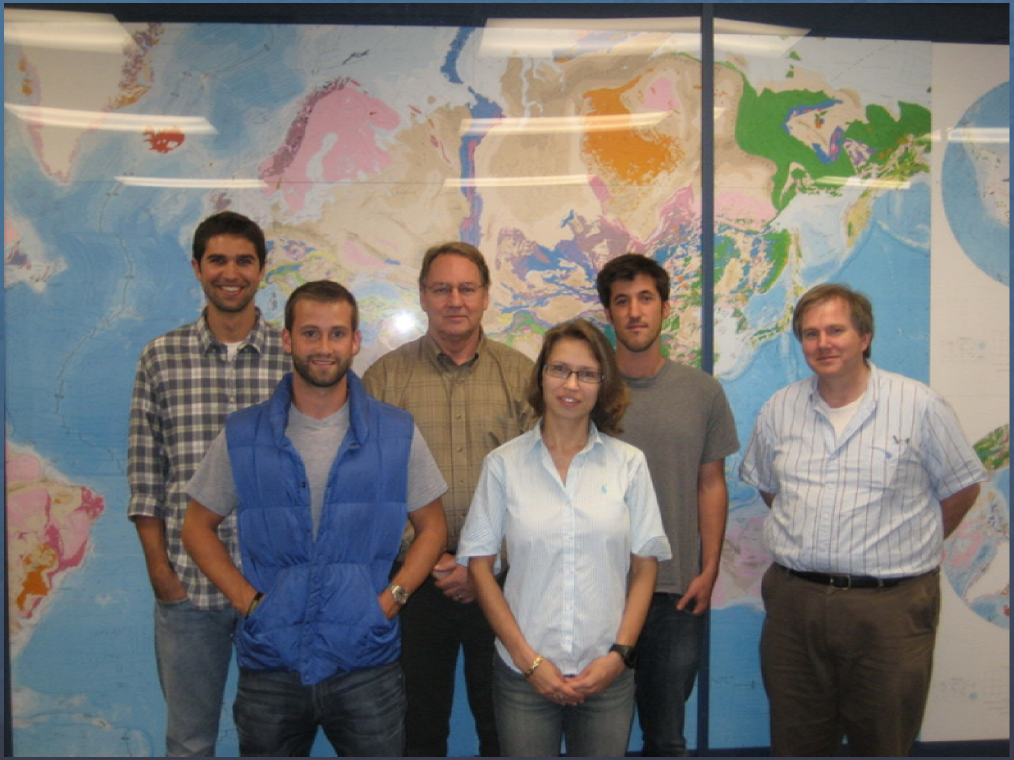
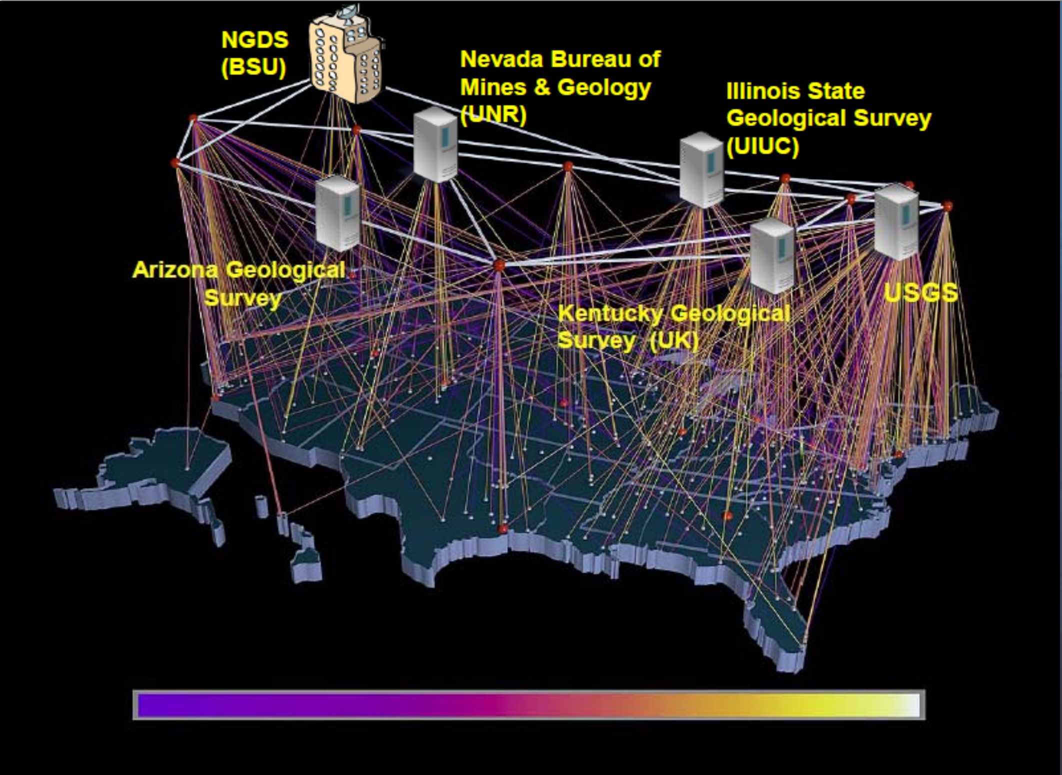
Kyle Kampa Research Assistant (1/3 time)
Adam Stater Research Assistant

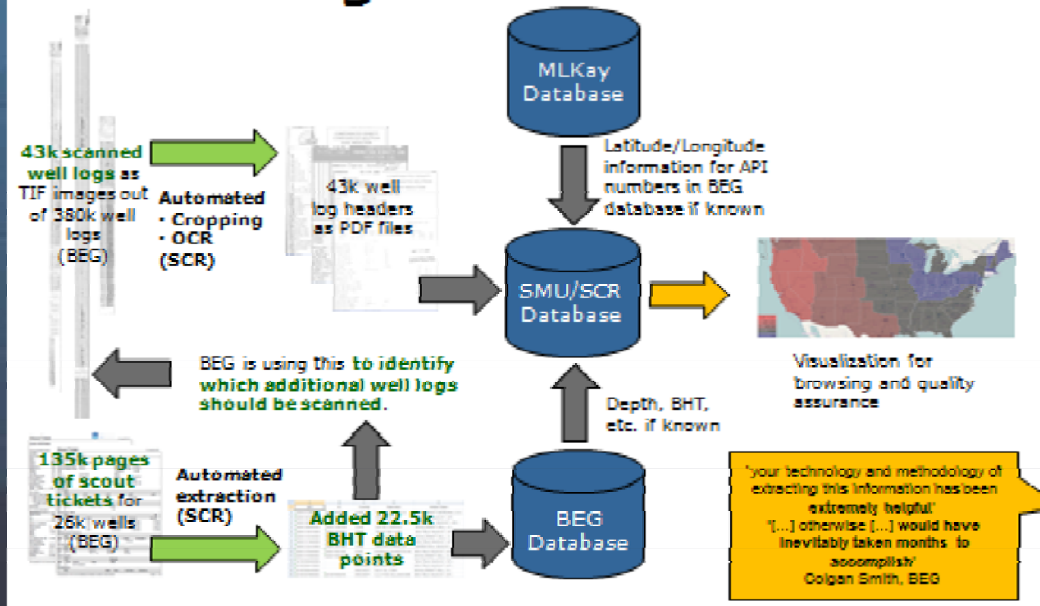


NGDS

National Geothermal Data System



SMU/Siemens - Well log data integration workflow



A Review: Interest in Geothermal Energy has been revived by two important investigations:

1. **The Future of Geothermal Energy (2006**) known as the MIT Study.
   - focused on Engineered Geothermal Systems; i.e., hydrofracked reservoirs, but predominantly in crystalline rock.
   - concluded that there may be available for extraction the equivalent of 2000 times the annual energy consumption of the United States

2. **Geothermal Risk Mitigation Strategies Report; (2008)** known as the Deloitte Study
   - Originated as a result of the MIT Study.
   - “if the MIT Study says geothermal is such a great idea, why aren’t we investing more in development”?
   - Concluded development was not occurring because;
     - A lack of transmission infrastructure
     - A Lack of reliable information
     - A lack of policy continuity and clarity
     - Perceived high risk in early development

Engineered Geothermal Systems and the Transformation of Hydrofracted Natural Gas Reservoirs to Geothermal Energy Production

The Deloitte Study identified these key concerns:

- A lack of transmission infrastructure
- A Lack of reliable information
- A lack of policy continuity and clarity
- Perceived high risk in early development

- Densely drilled wells, some as close as every 40 acres, and located in urban areas addresses the concerns of transmission infrastructure
- The soon to be available database addresses the need for reliable information on the subsurface, and
- Reduces the uncertainties, and therefore the perceived risk in the early development phase
- In Texas, the legal definition of geothermal heat as a mineral resource has provided some needed clarity in regulatory policy

The Transformation of Hydrofracked Reservoirs to Geothermal Energy Production

I. KEY QUESTIONS:

A. Stored Heat, how much is present

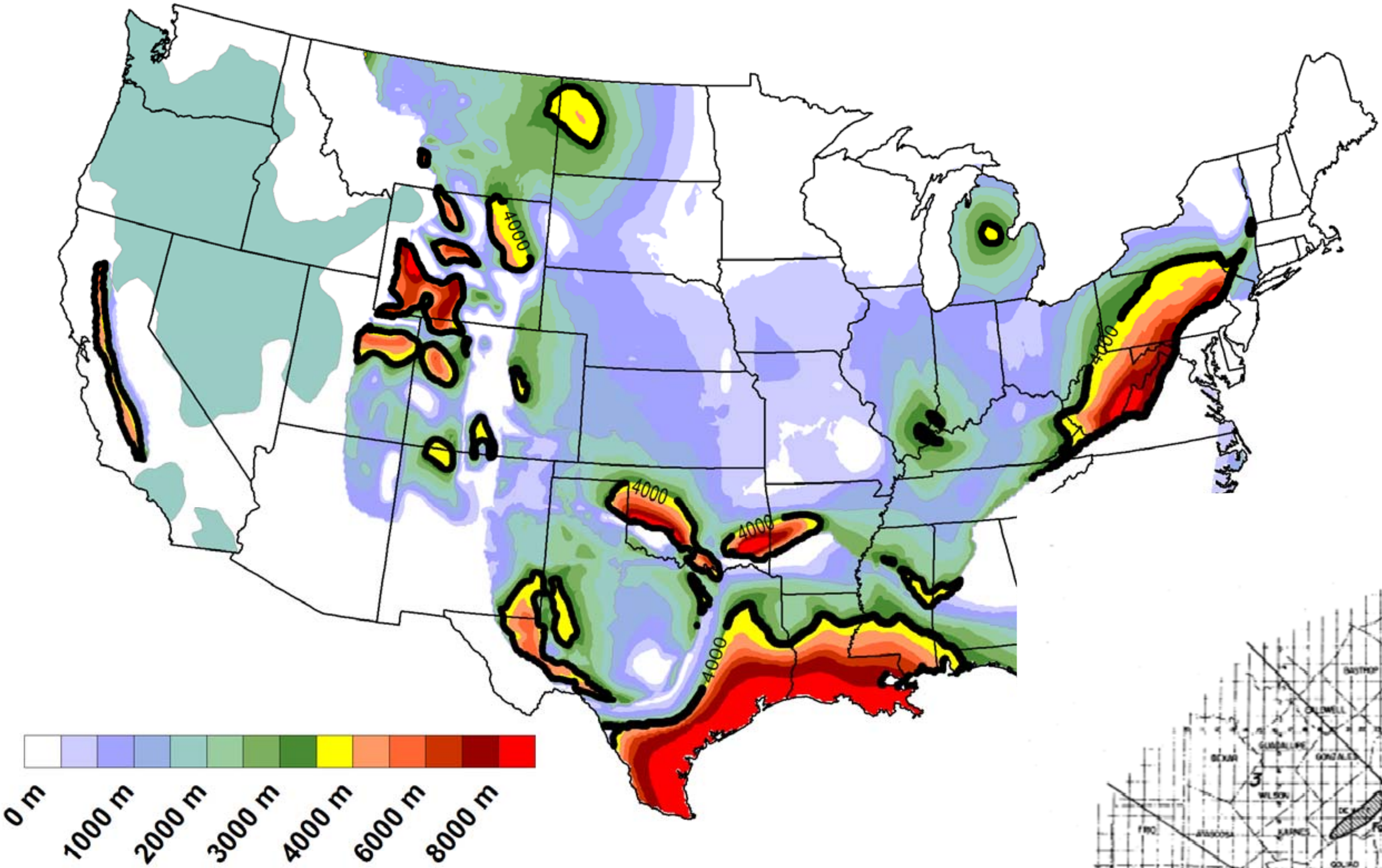
B. Extractable Heat, i.e., what can be recovered from the subsurface formation, and surrounding units, for use at the surface?

C. What is the Conversation Efficiency at the Surface? From thermal energy to electricity, what about entrained gas? What about excess pressure?

D. Can Individual Extraction Points be Integrated into a Distributed Energy Generating System?

E. Does Any of This Make Economic Sense? Is Geothermal Energy from Deep Sediments Economically Competitive with Coal, Natural Gas, Wind, Solar, Biofuels?


What we don’t have
Iceland 18 MW well



Sediment Thickness Map of US

(from “The Future of Geothermal Energy” MIT 2006)

From RI 91,
Bebout, Loucks and
Gregory, 1978

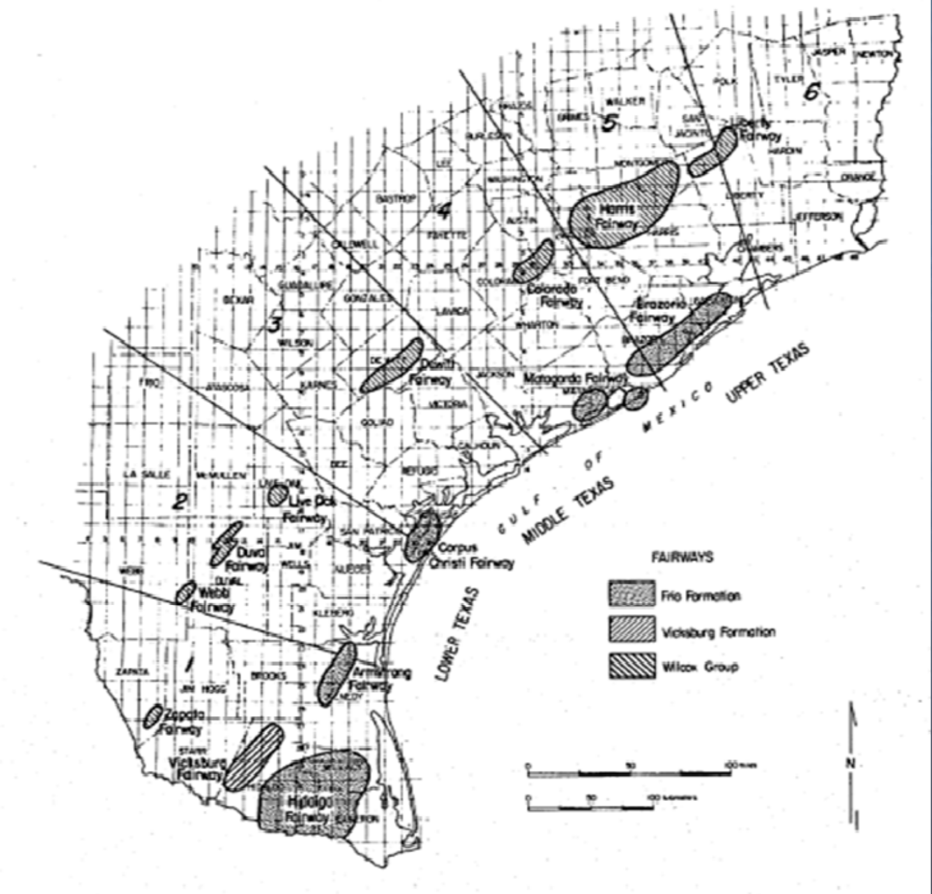
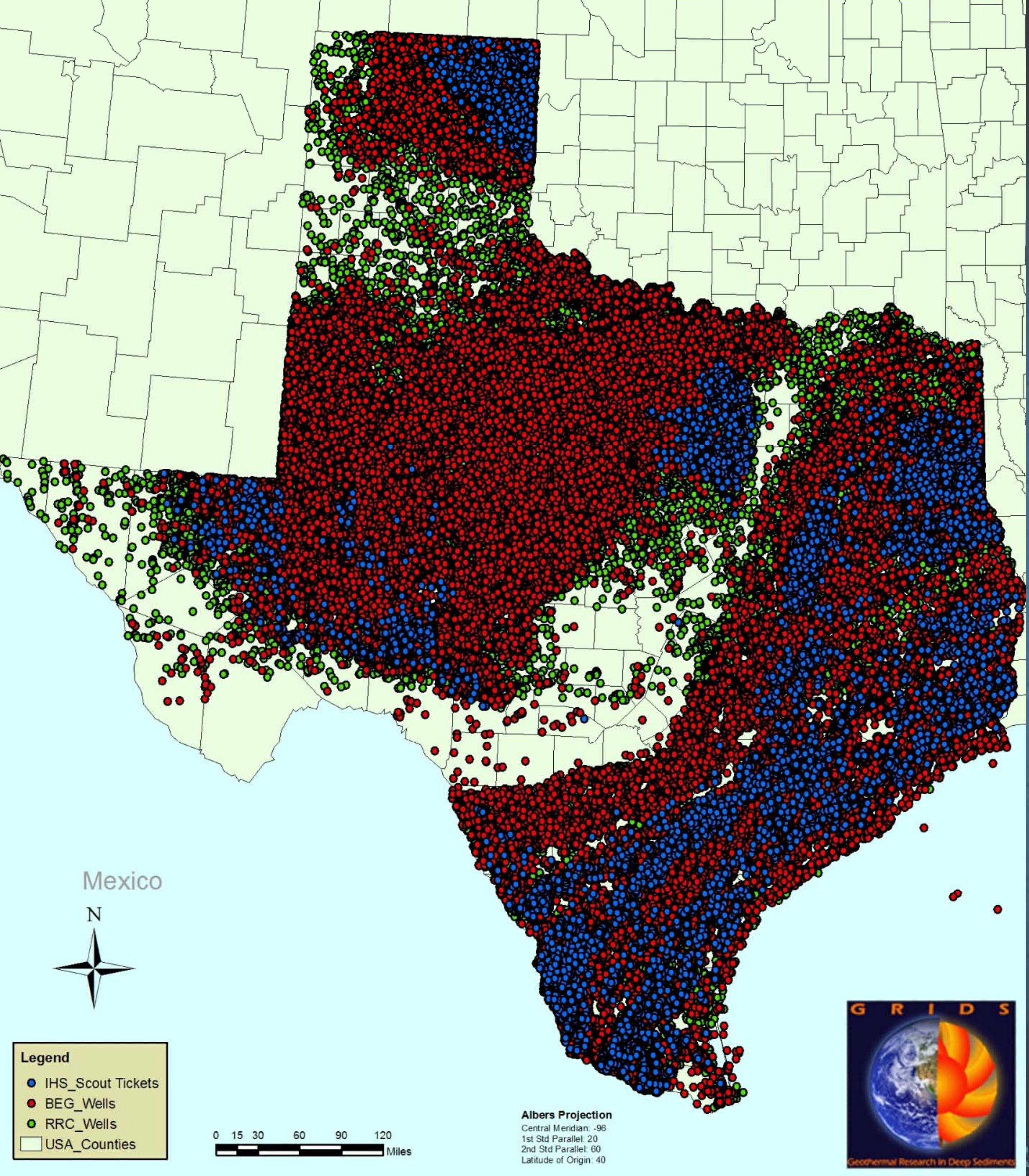
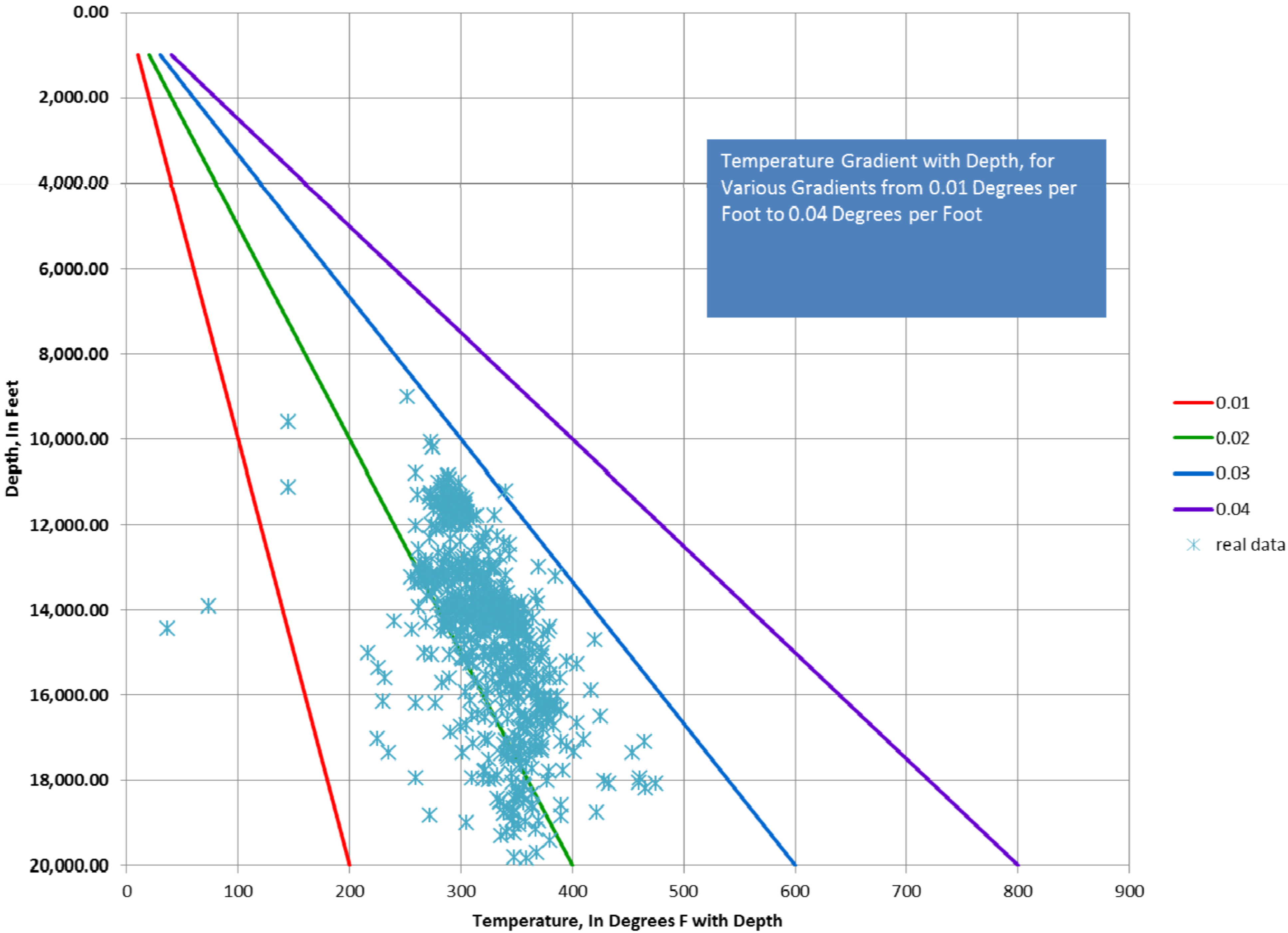


Figure 1. Area of investigation showing geopressured geothermal fairways and division of Lower, Middle, and Upper Texas Gulf Coast areas.

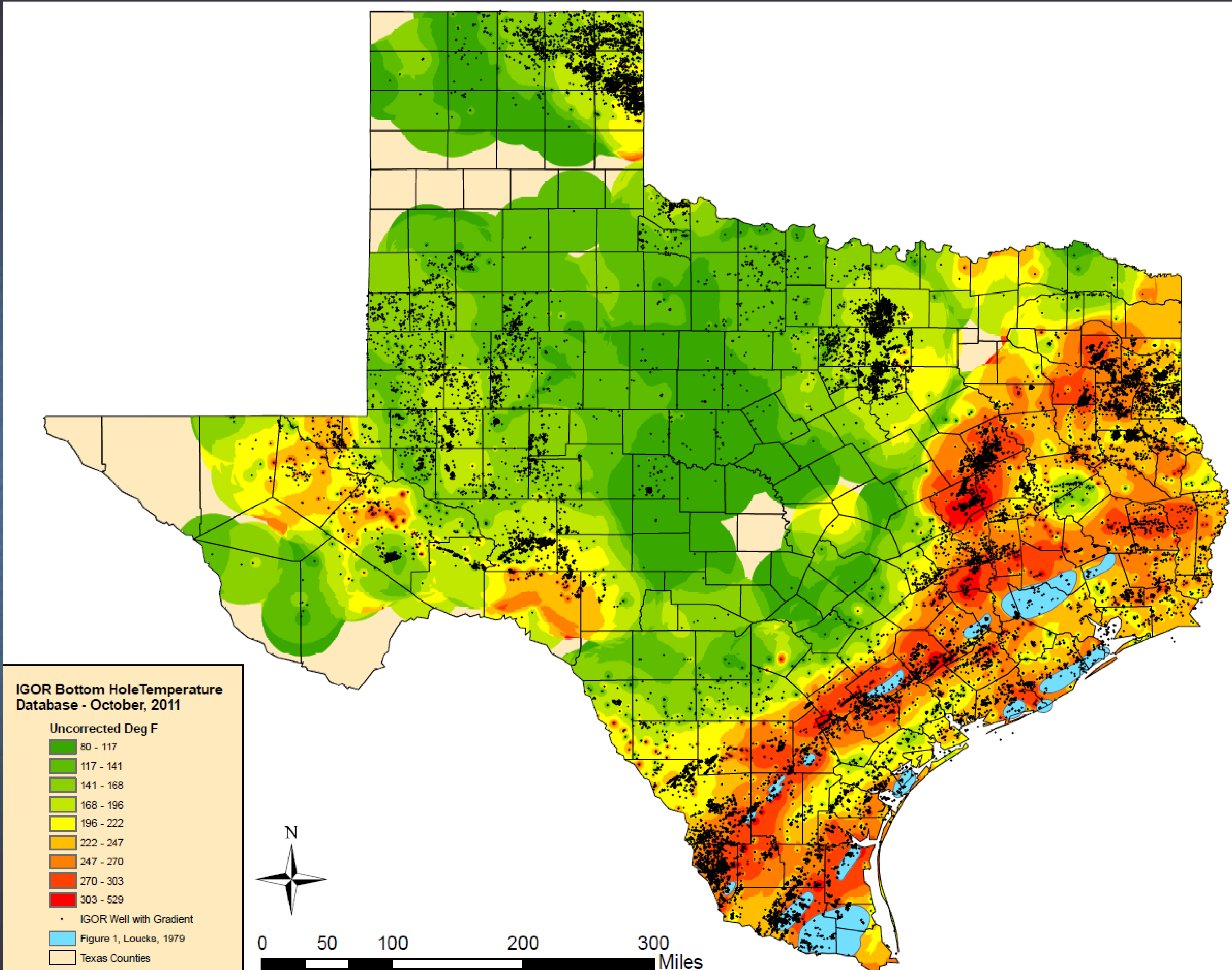


Existing wells in Texas with some type of accessible information in electronic form.

- Total wells in Texas estimated at 1.2 to 1.4 million.
- ..with electronic information, approximately 780,000+/-
- …and potentially useful information estimated at 300,000.



BUREAU OF ECONOMIC GEOLOGY


IGOR Bottom HoleTemperature Database - October, 2011
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IGOR Well with Gradient
Figure 1, Loucks, 1979
Texas Counties
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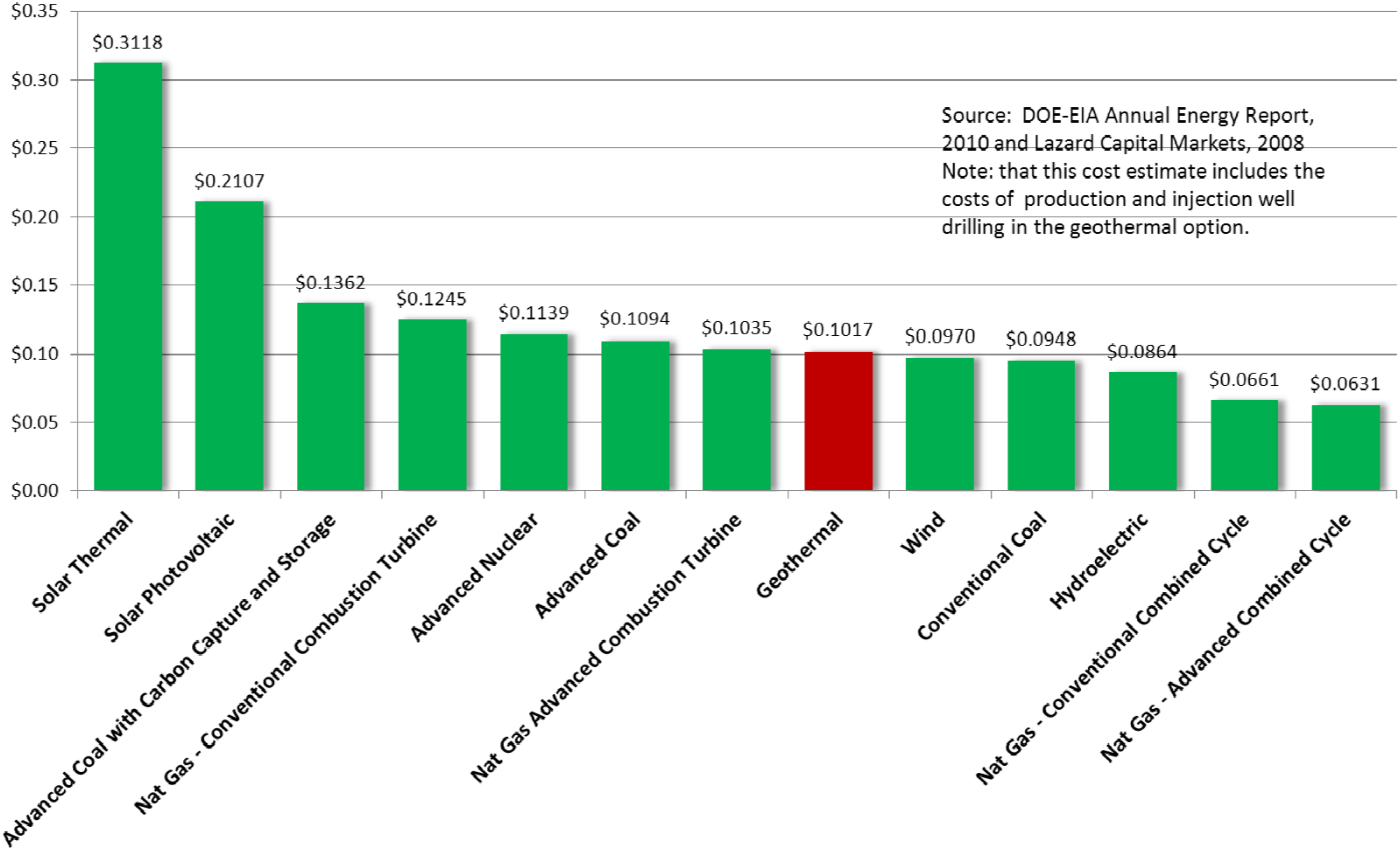
100
200
300
Miles

Comparison of Total System Levelized Cost for Various Methods of Electricity Generation ($/KWhr)



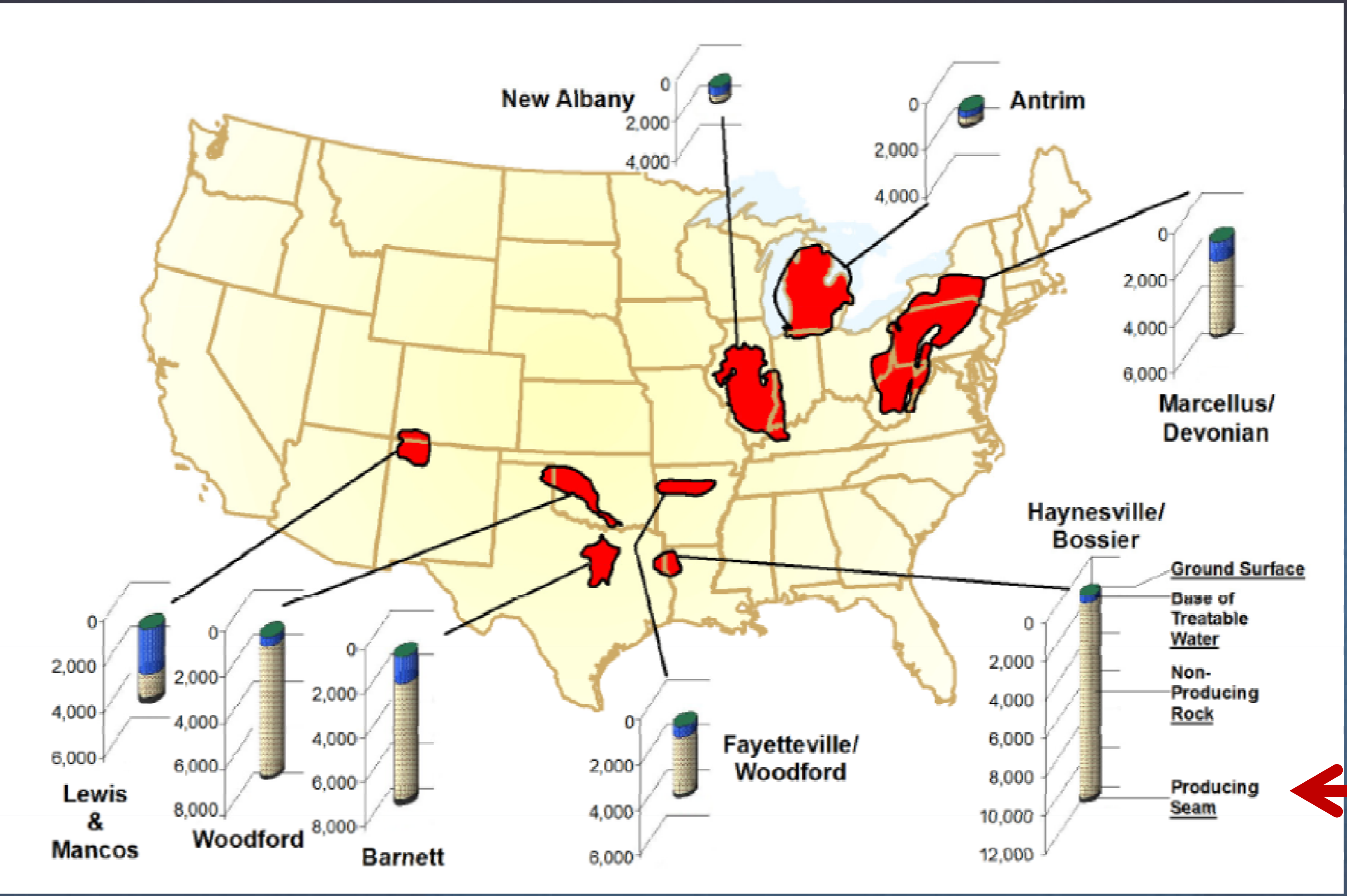
- In o*ur efforts to estimate the magnitude of the (known) resource, we may have neglected a* viable area that is now being developed by the natural gas industry and specifically by the hydrofracturing process of developing tight gas formations.
- …*it is always easier to leverage other peoples effort, and investment….*

- Reservoir improvement using hydrofracing techniques has completely transformed the natural gas industry.

  - Mitchell Energy created a revolution in the petroleum industry.

  - *Pre-Mitchell Energy, Fenton Hill failed, because of inadequate technology, and experience.*
  - *Cooper Basin, Australia is struggling, because of a lack of technology transfer.*

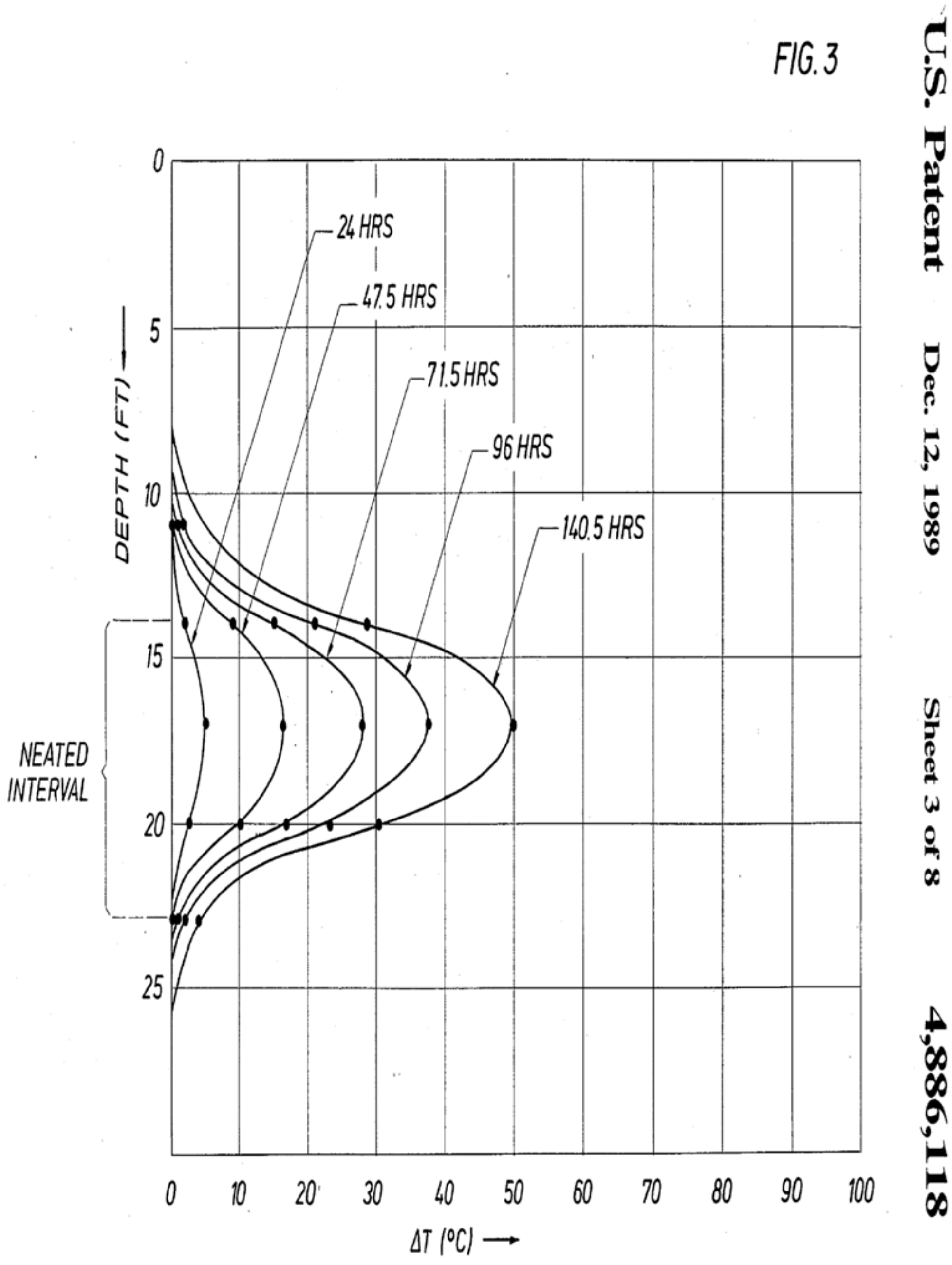
  - **Geothermal Energy from Deep Hot Sediments can Succeed because of Mitchell Energy and the transfer of technology and pre-invested capital from the Petroleum Industry.**

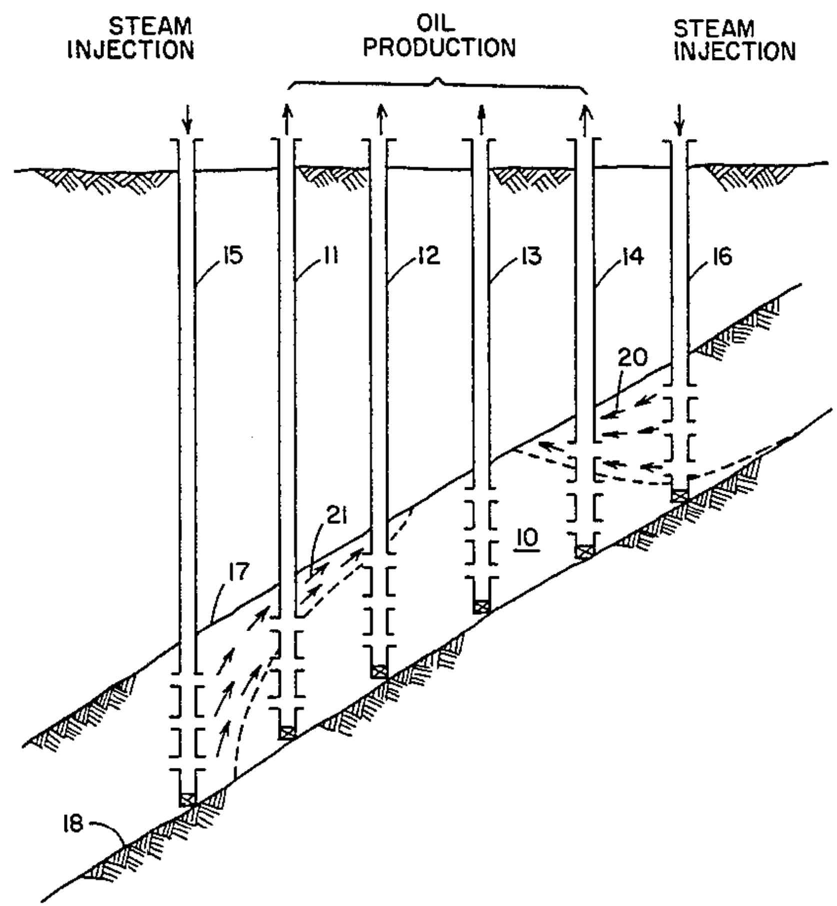


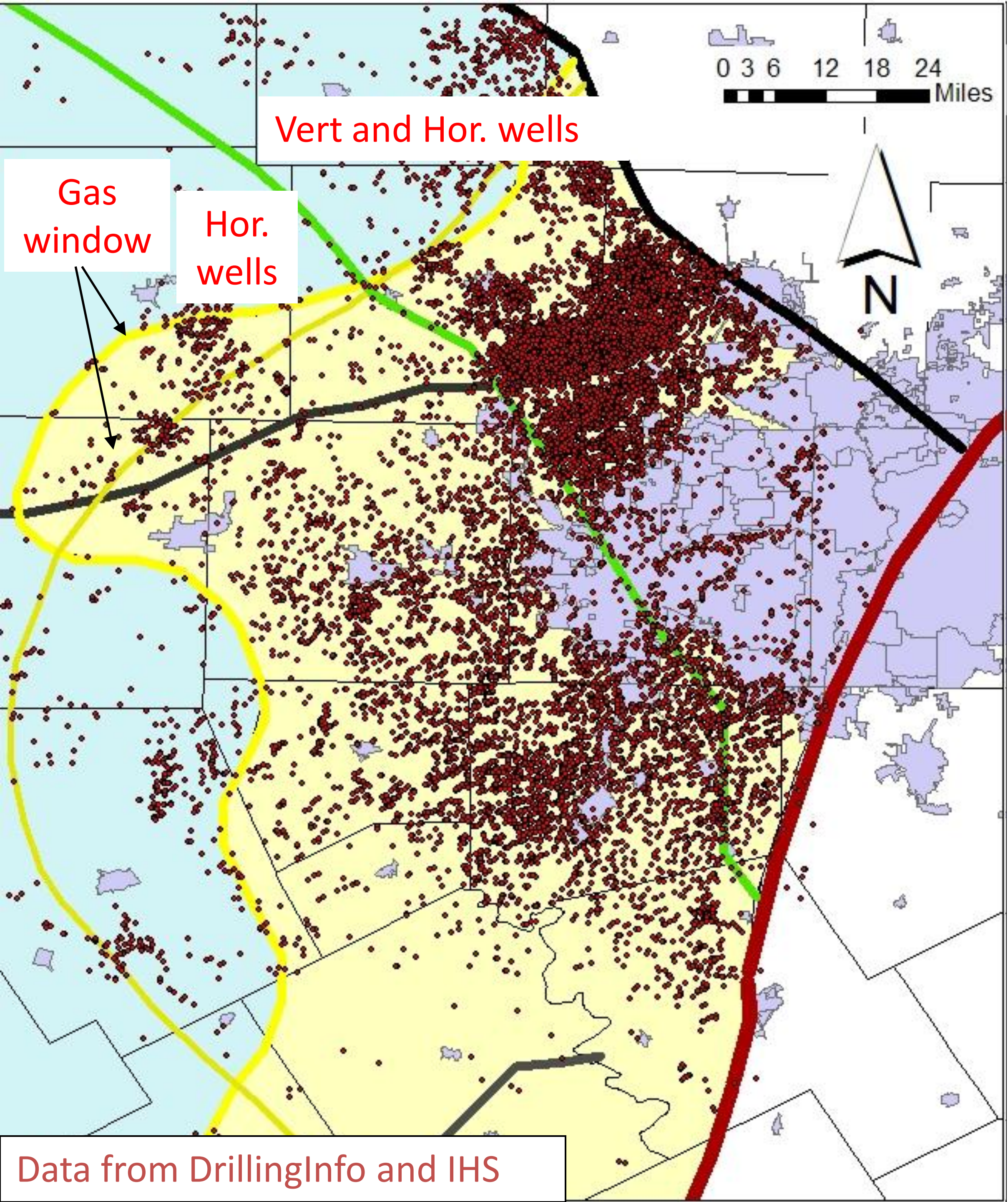
Gas production from the Haynesville/Bossier is from depths where formation temperatures are well above 250 ^{0}F

- So, how do we assess the significance of this potential geothermal resource?
  - Early work in extracting oil from oil shales in the 1970s and 1980s provided good information on heat-rock interactions for in-situ retort processes.
  - Reverse this process, and heat extraction can be calculated.

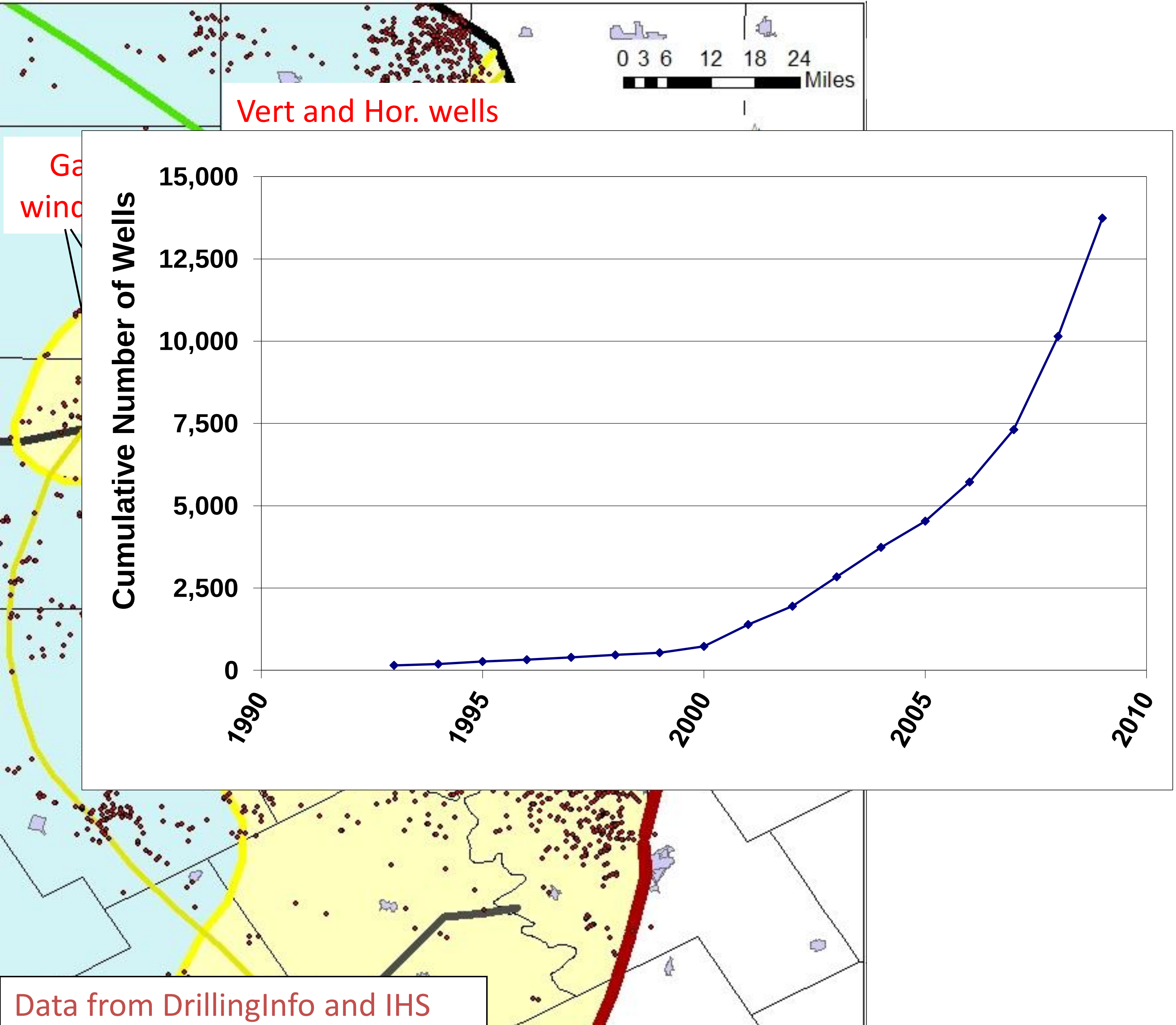
Patent Filed Feb 17th 1988, held by Shell Oil Company.







0 3 6 12 18 24
Miles
N
Vert and Hor. wells
Gas window
Hor. wells
Data from DrillingInfo and IHS



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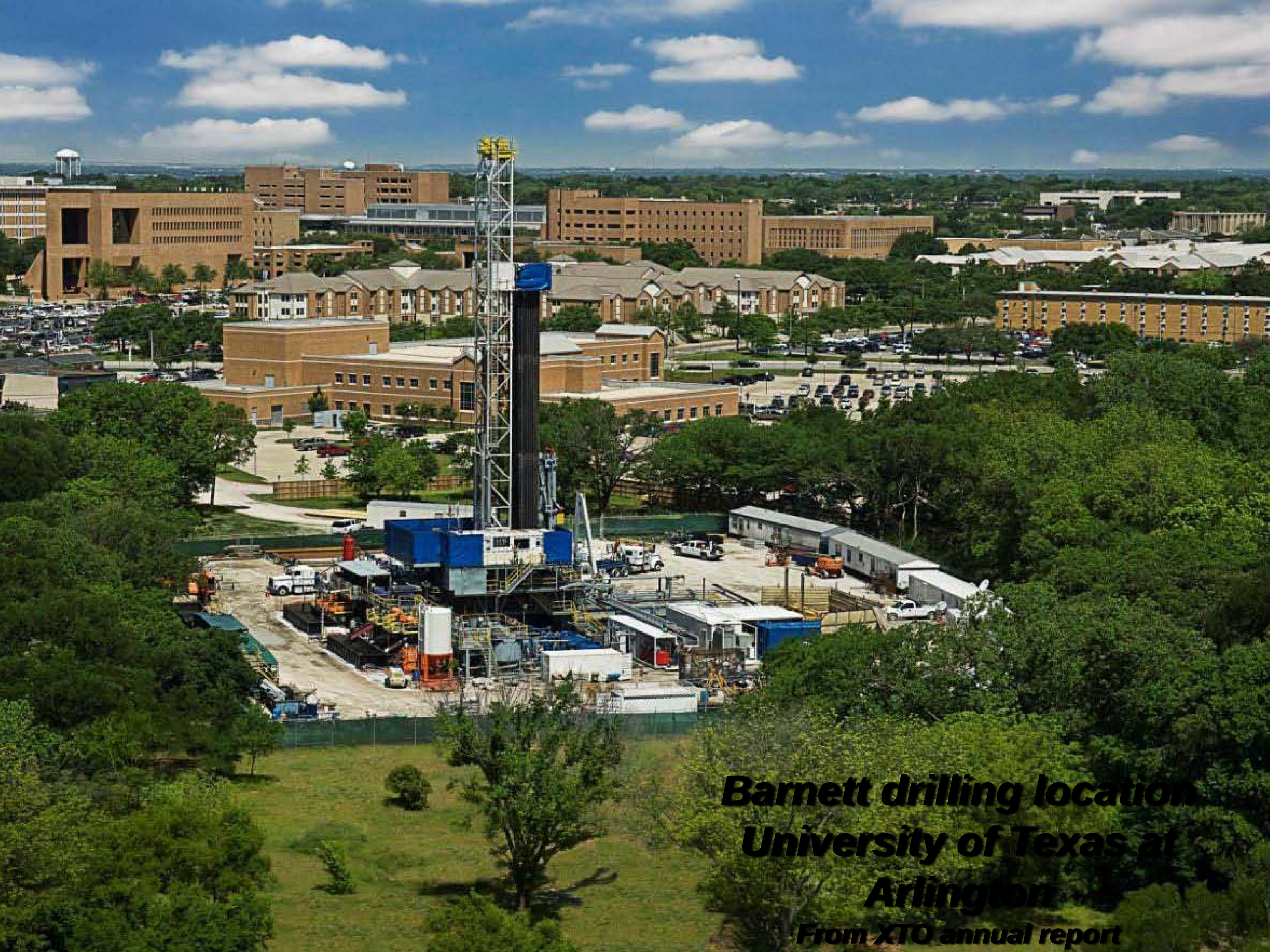
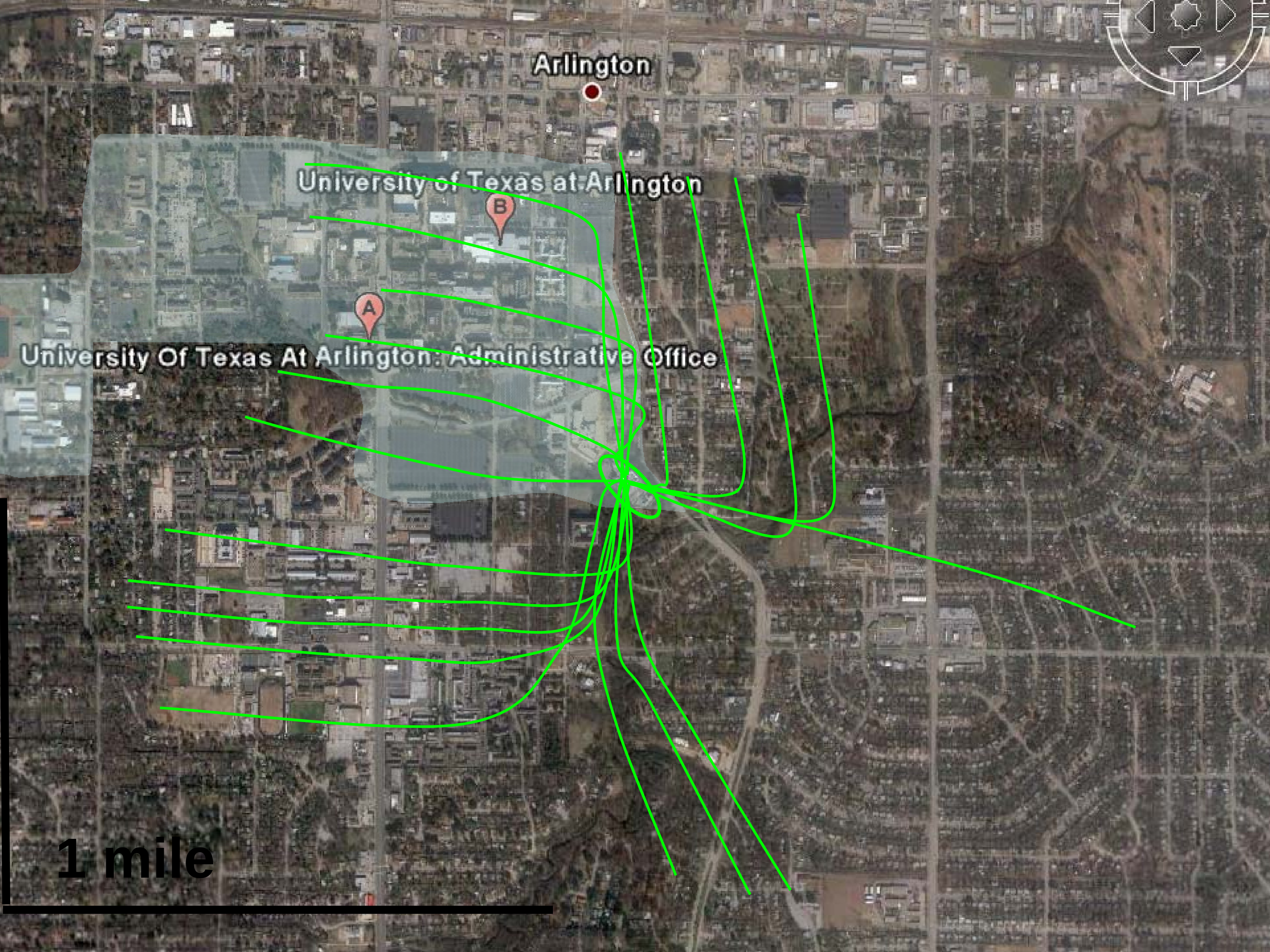
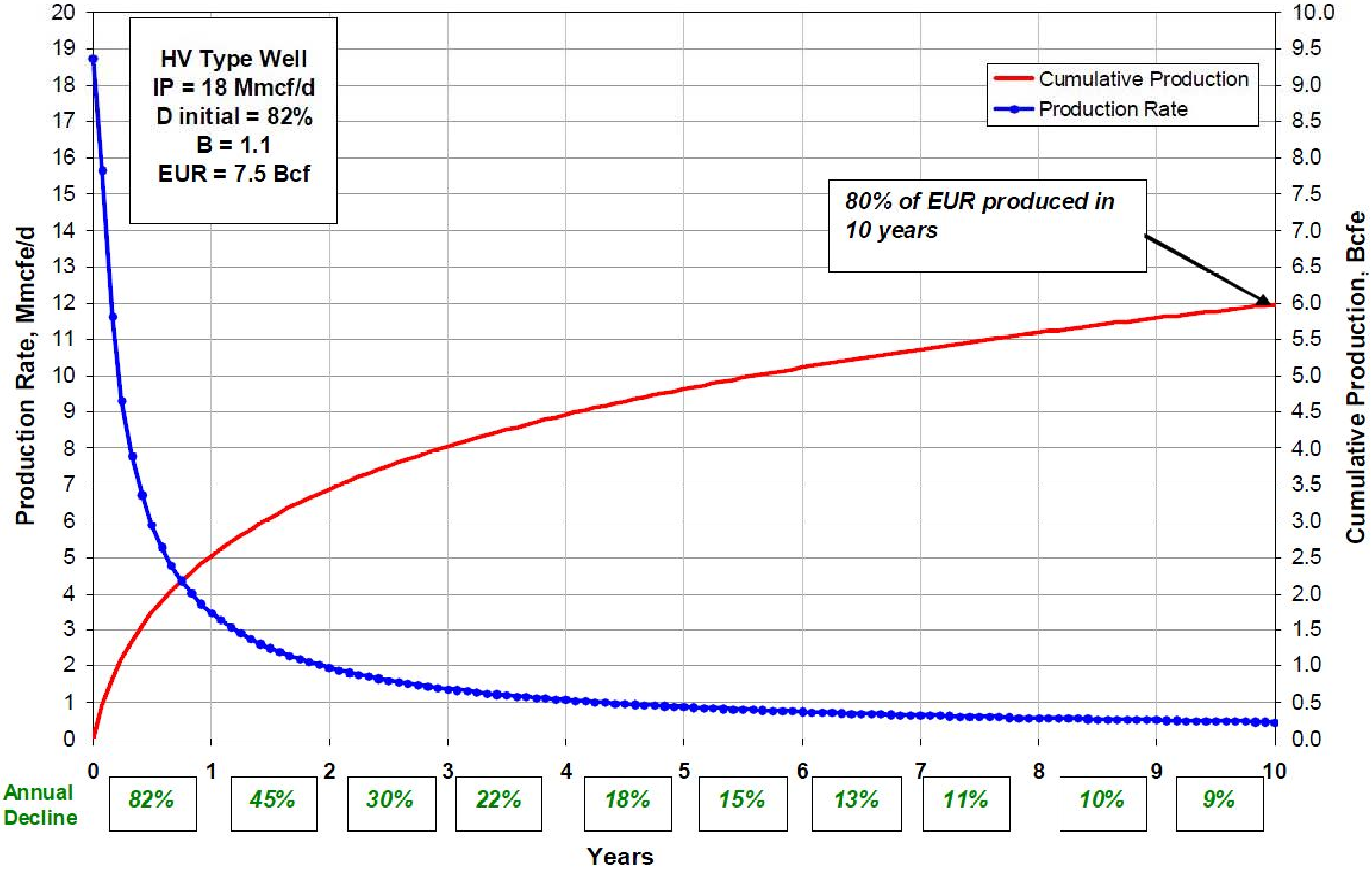


Barnett drilling location University of Texas at Arlington

From XTO annual report


Arlington
University of Texas at Arlington
B
A
University Of Texas At Arlington: Administrative Office
1 mile

Current Haynesville Shale Type Curve

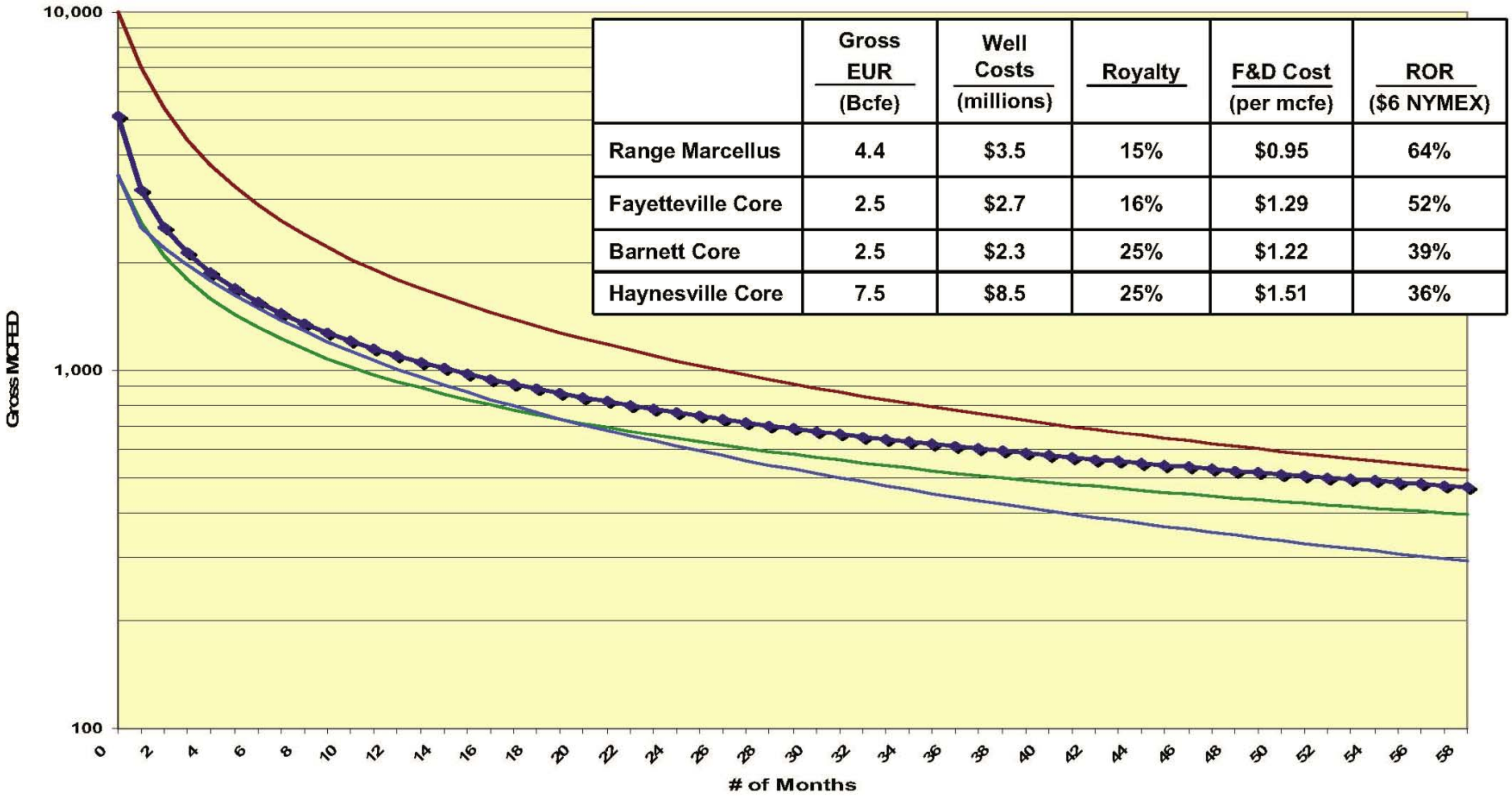


*Petrohawk's estimated type curve for wells produced typically on a 24/64" choke

13

There is a serious problem, however, with production from the fractured shale reservoirs.

Shale Play Comparison

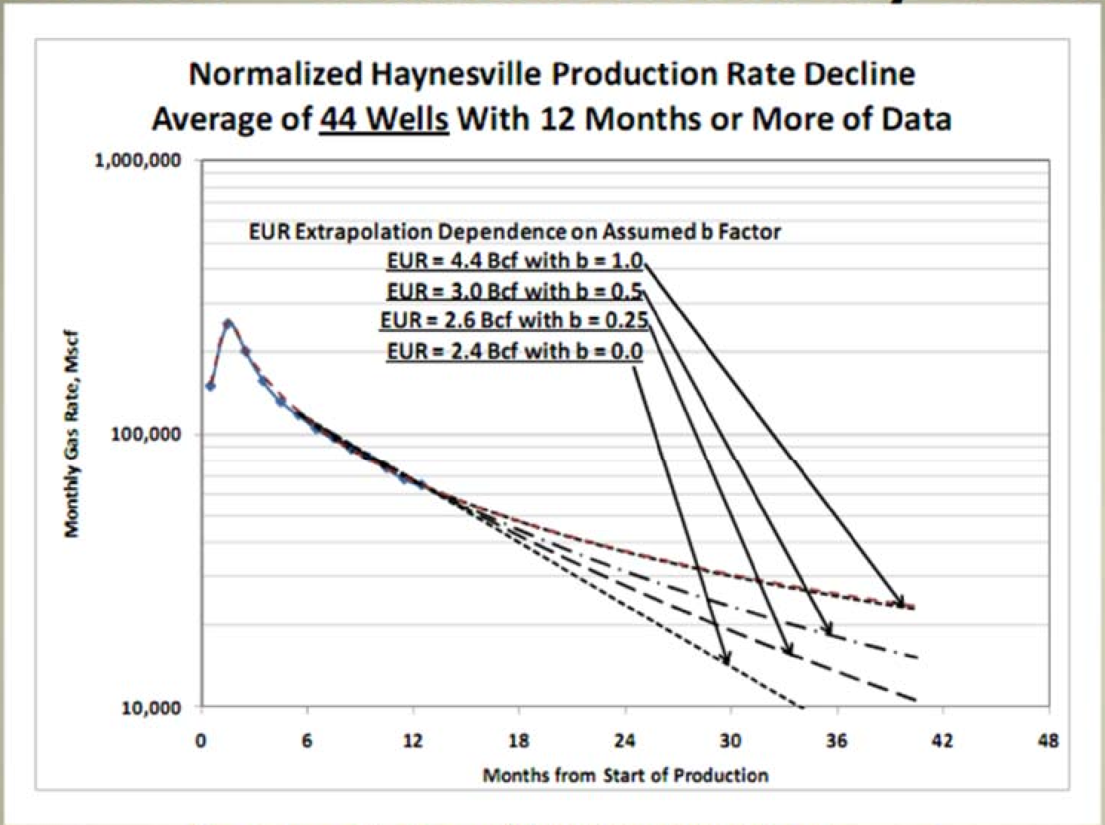


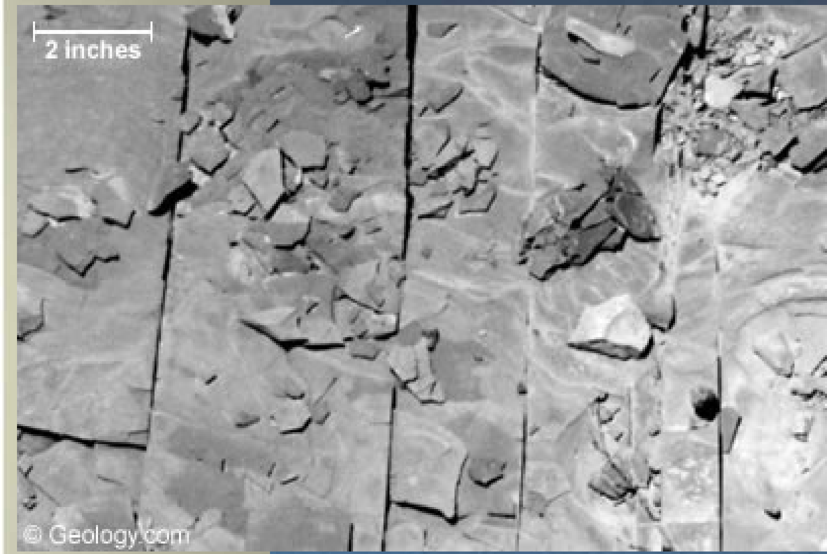
	Gross EUR (Bcfe)	Well Costs (millions)	Royalty	F&D Cost (per mcfe)	ROR ($6 NYMEX)
Range Marcellus	4.4	$3.5	15%	$0.95	64%
Fayetteville Core	2.5	$2.7	16%	$1.29	52%
Barnett Core	2.5	$2.3	25%	$1.22	39%
Haynesville Core	7.5	$8.5	25%	$1.51	36%

- **Type curves for Barnett, Fayetteville and Haynesville based on public production information**
- **Zero time curve for Marcellus based on production results from 24 Range wells only**

Source: Range Resources in G. MacFarland, Oil & Gas Evaluation Report. March 17, 2010

Haynesville – Ultimate Recovery & Economics





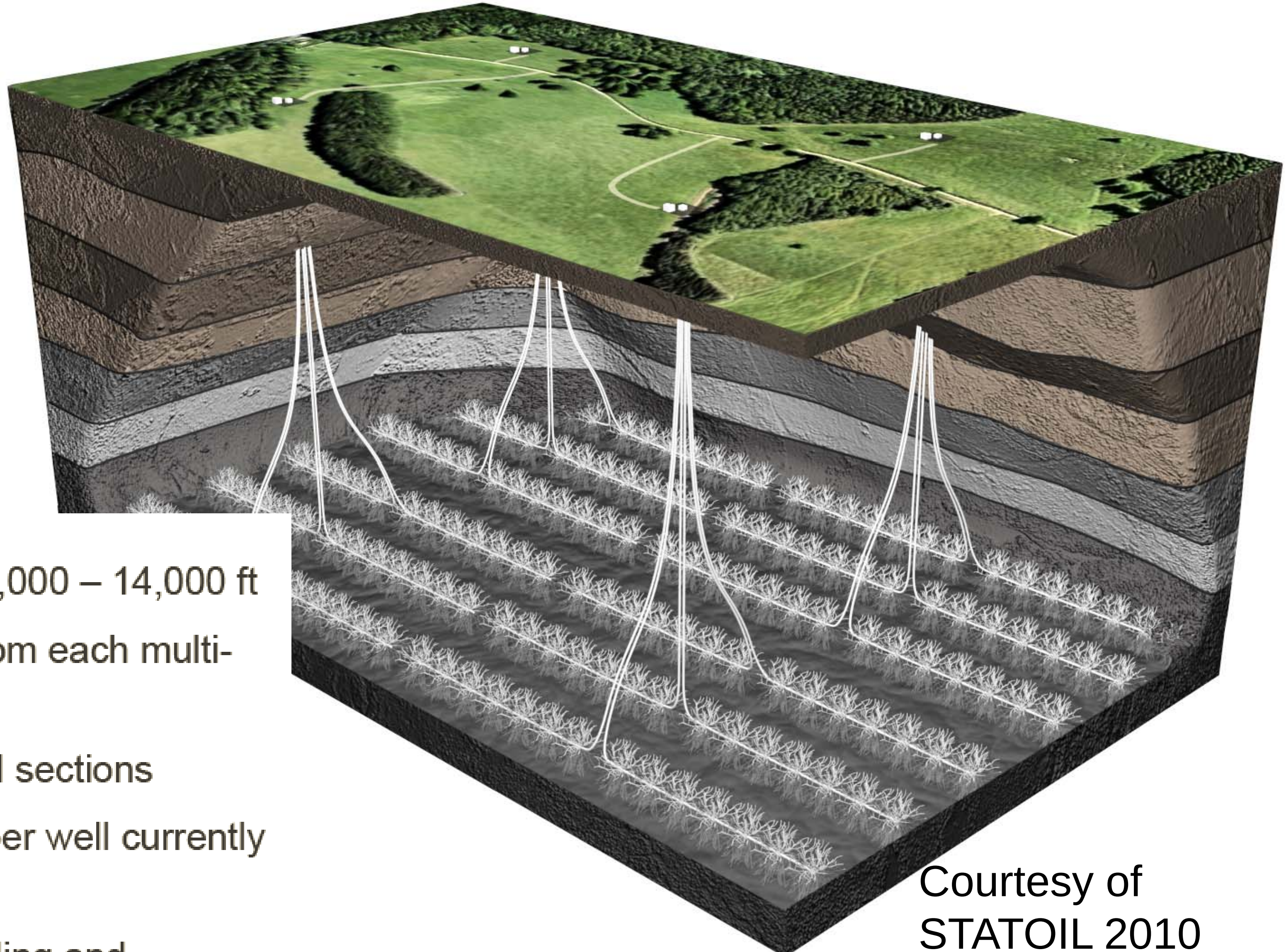
Breakeven Gas Price, $/MMBtu @ Wellhead

(at 10% Discount Rate)

EUR Scenario	EUR/Well, Bcf	Full Cycle
Group Avg, Projected w/ b = 0	2.3	$9.00
Group Avg, Projected w/ b = 0.5	3.0	$7.80
Group Avg, Projected w/ b = 1.0	4.4	$6.70
Operator View, 14 MMsfd IP, b=1.07	6.5	$4.70

$8MM/well, $5,000/acre, 120 acre/well, ½ of land leased is fully developed

Producing from the Eagle Ford

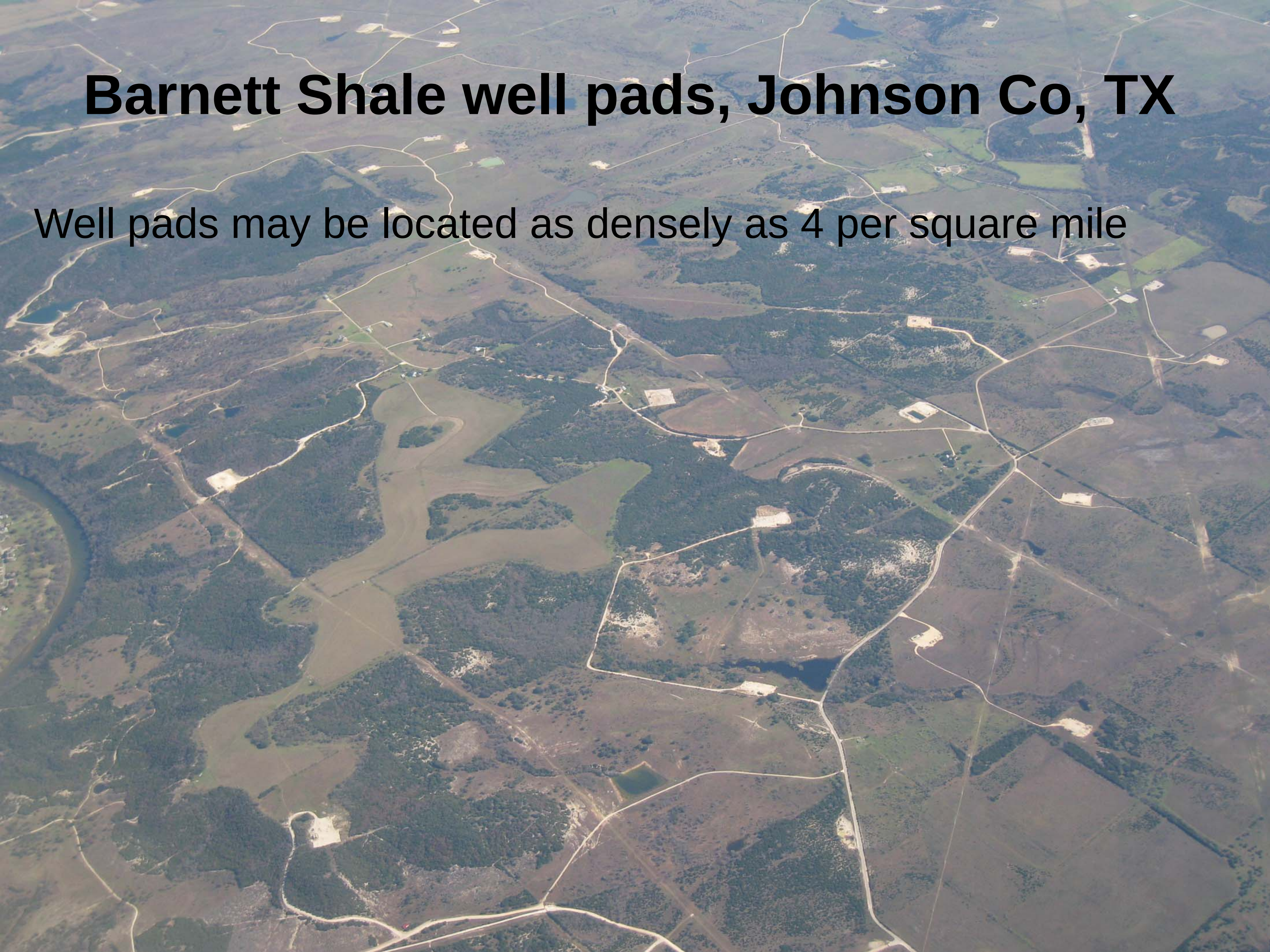


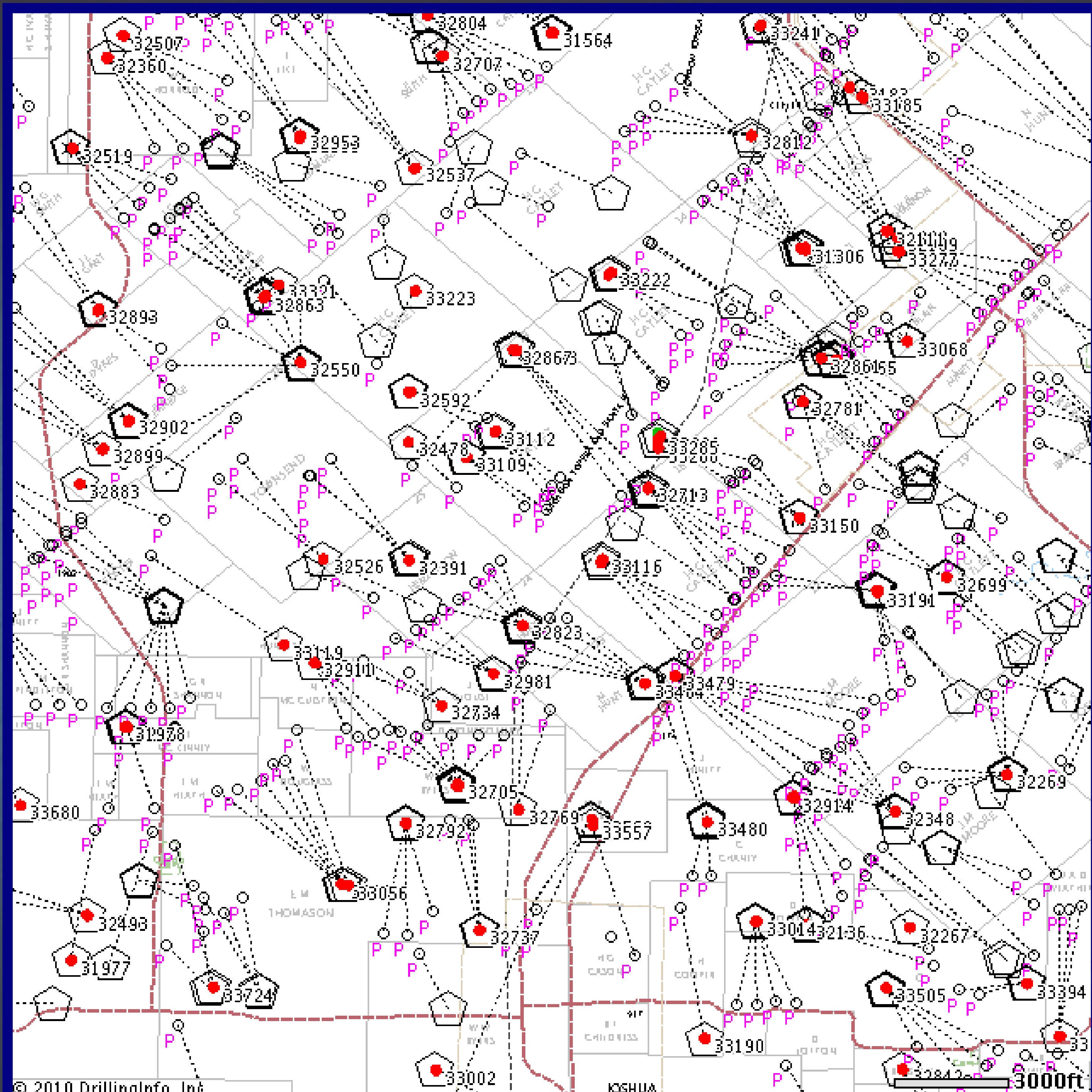
Courtesy of STATOIL 2010

- Reservoir located at 9,000 – 14,000 ft
- 4-8 horizontal wells from each multi-well pad
- 3,000 – 5,500 ft lateral sections
- Average drilling time per well currently 40 days
- Utilising horizontal drilling and hydraulic fracturing technology
- Decline from initial production rate but long tail production
- 55,000 acres of Enduring land already held by production (100%)

Barnett Shale well pads, Johnson Co, TX

Well pads may be located as densely as 4 per square mile

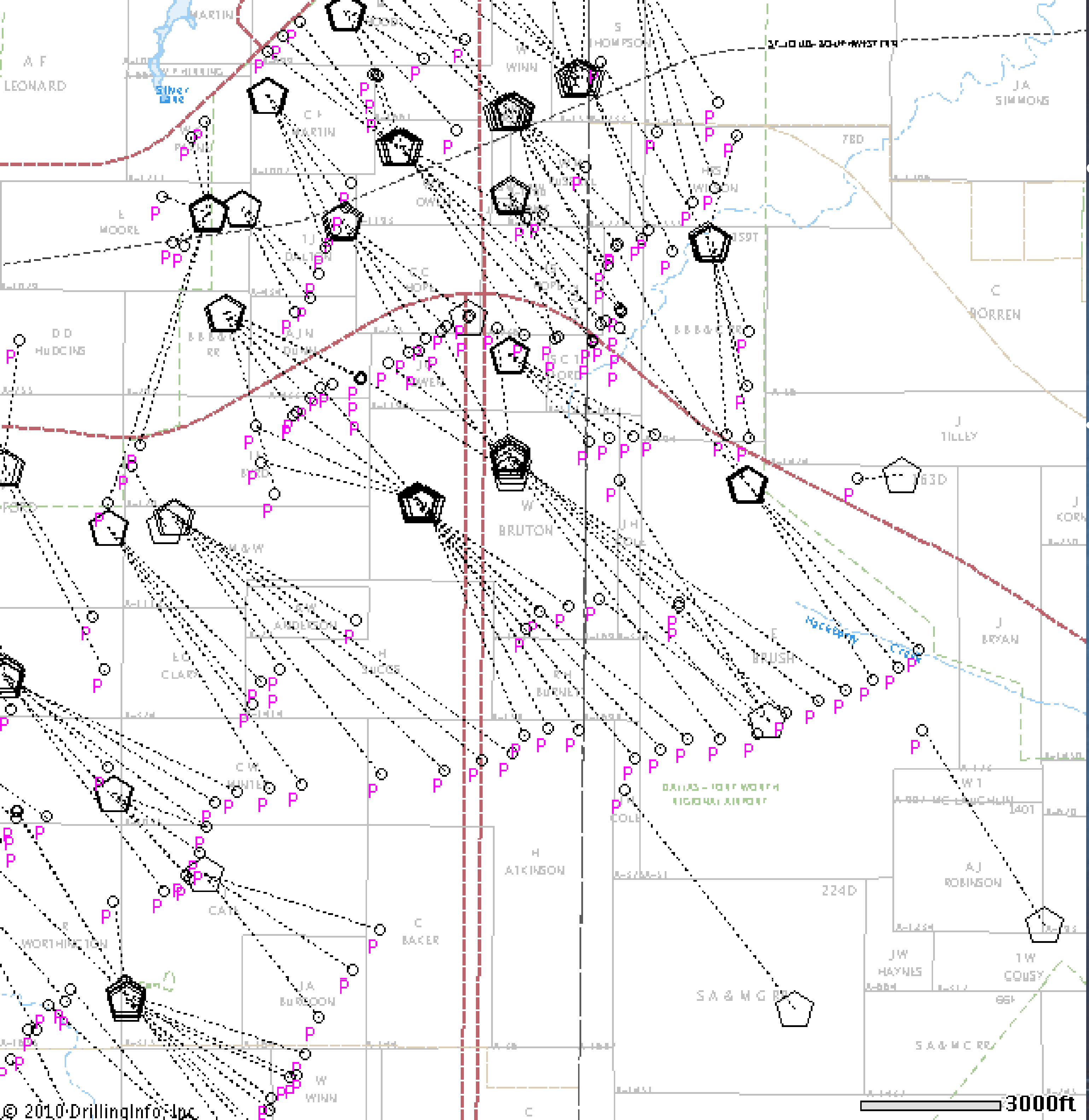




Horizontal wells
in Barnett Shale Play,
Johnson County, TX
April 2010

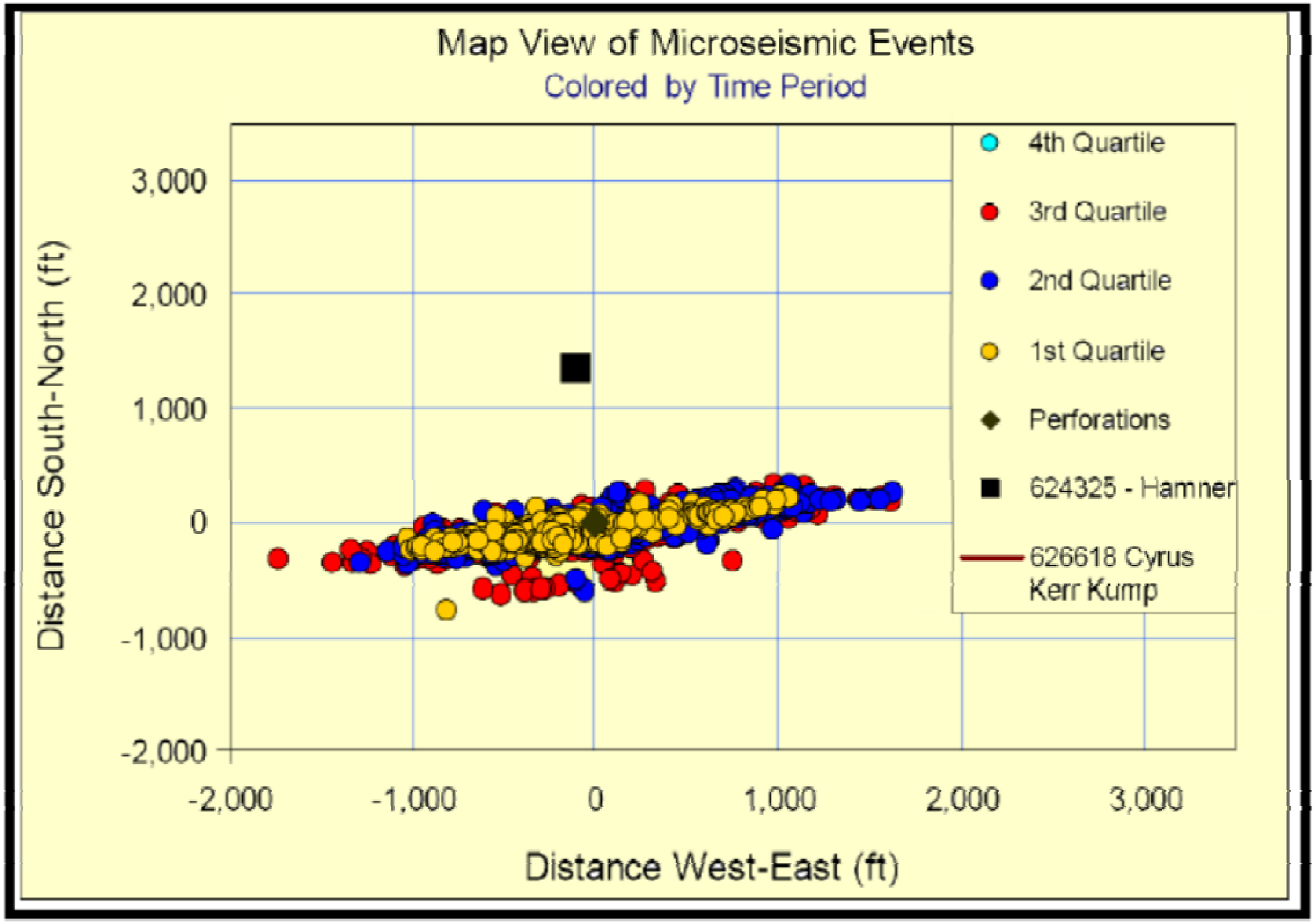
156 horizontal wells
in this view.

1 mile



- Example of Barnett Shale density of laterals (Dallas-Tarrant county line –

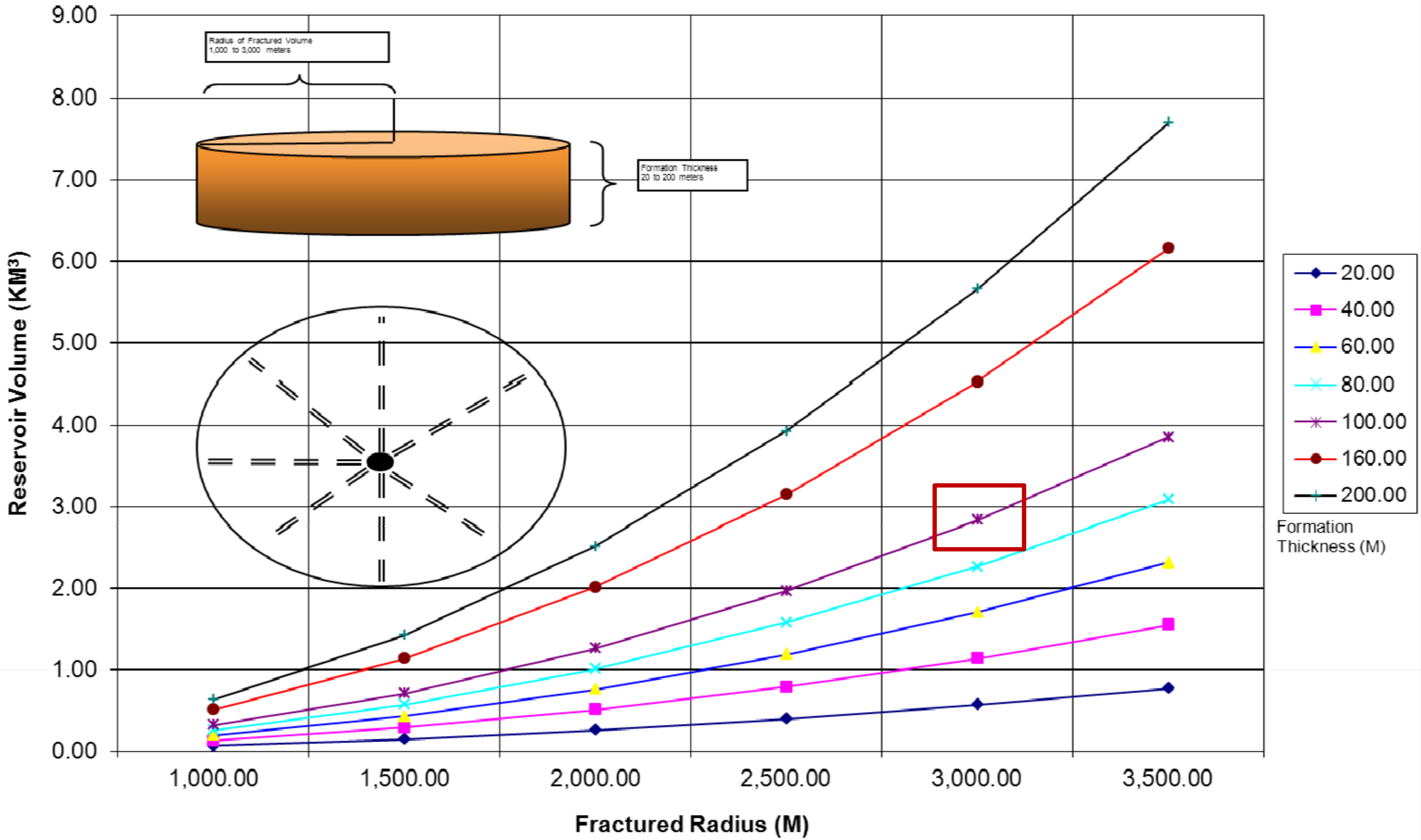
  DFW airport)
  - Source Courtesy of DrillingInfo



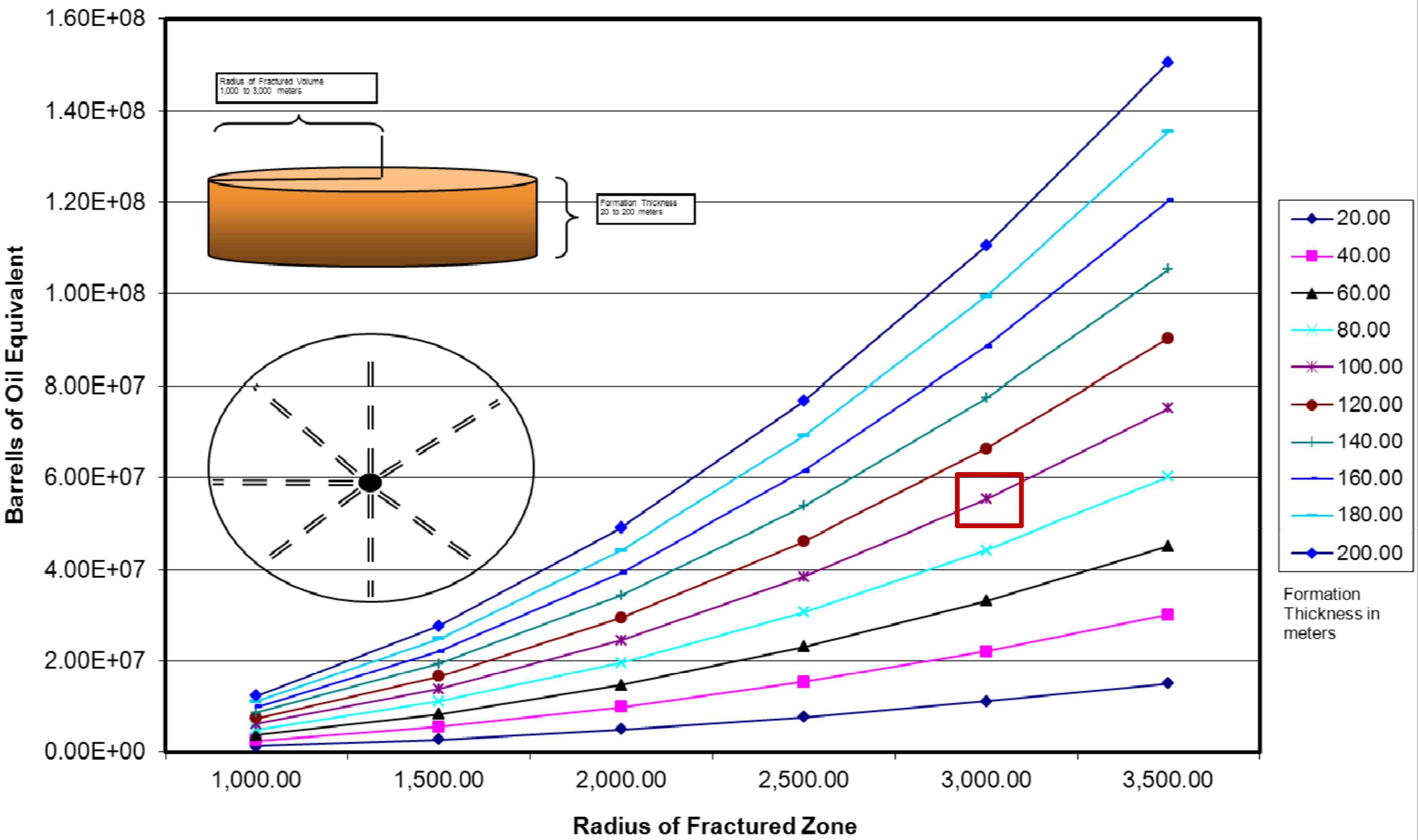
Source: Oilfield Service Company, 2008

Fracture orientation is controlled by in-situ stress field and formation fractures, joints and layering. Unfortunately, micro-seismic events do not (always) indicate extent of fracture. However, they do indicated the potential for fracture extension.

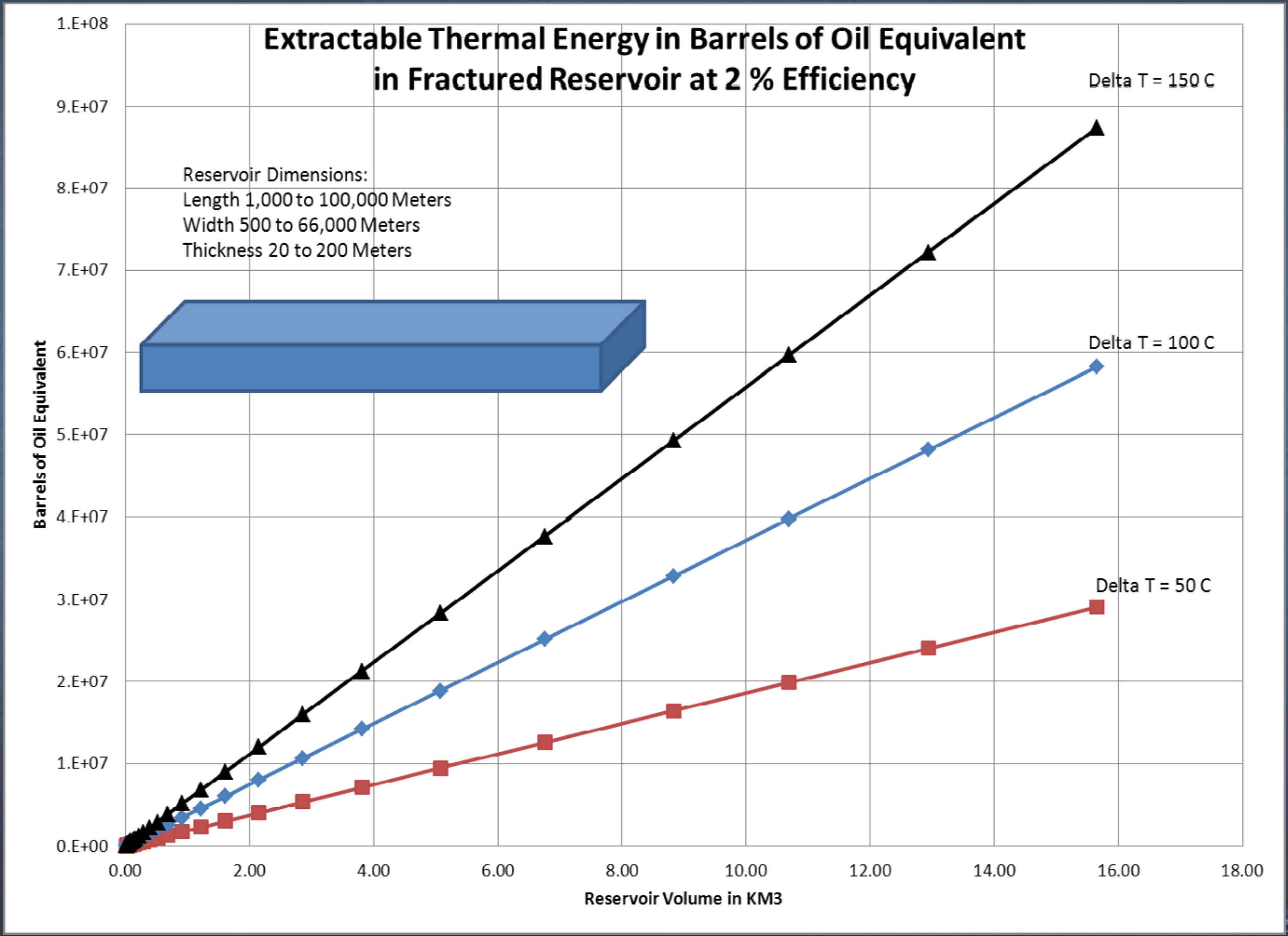
Fractured Reservoir Volume Created by Hydrofracturing Tight Shales

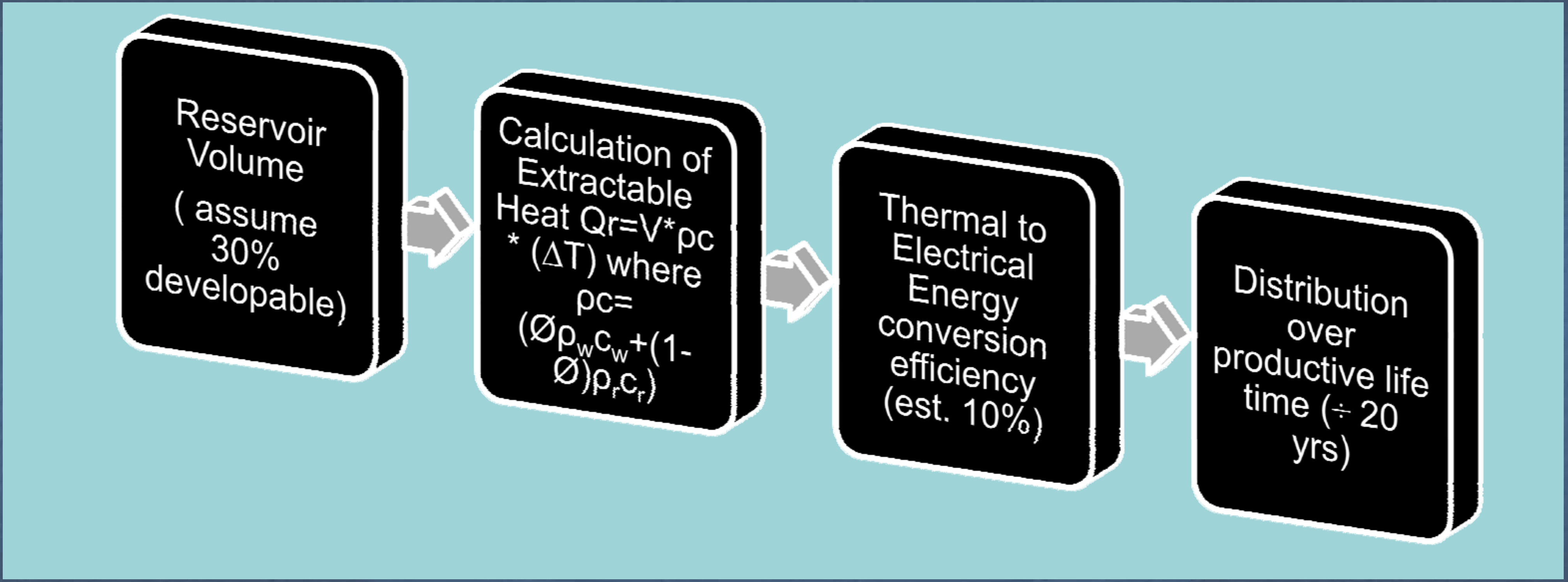


Thermal Energy in Bbls of Oil Equivalent



The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production

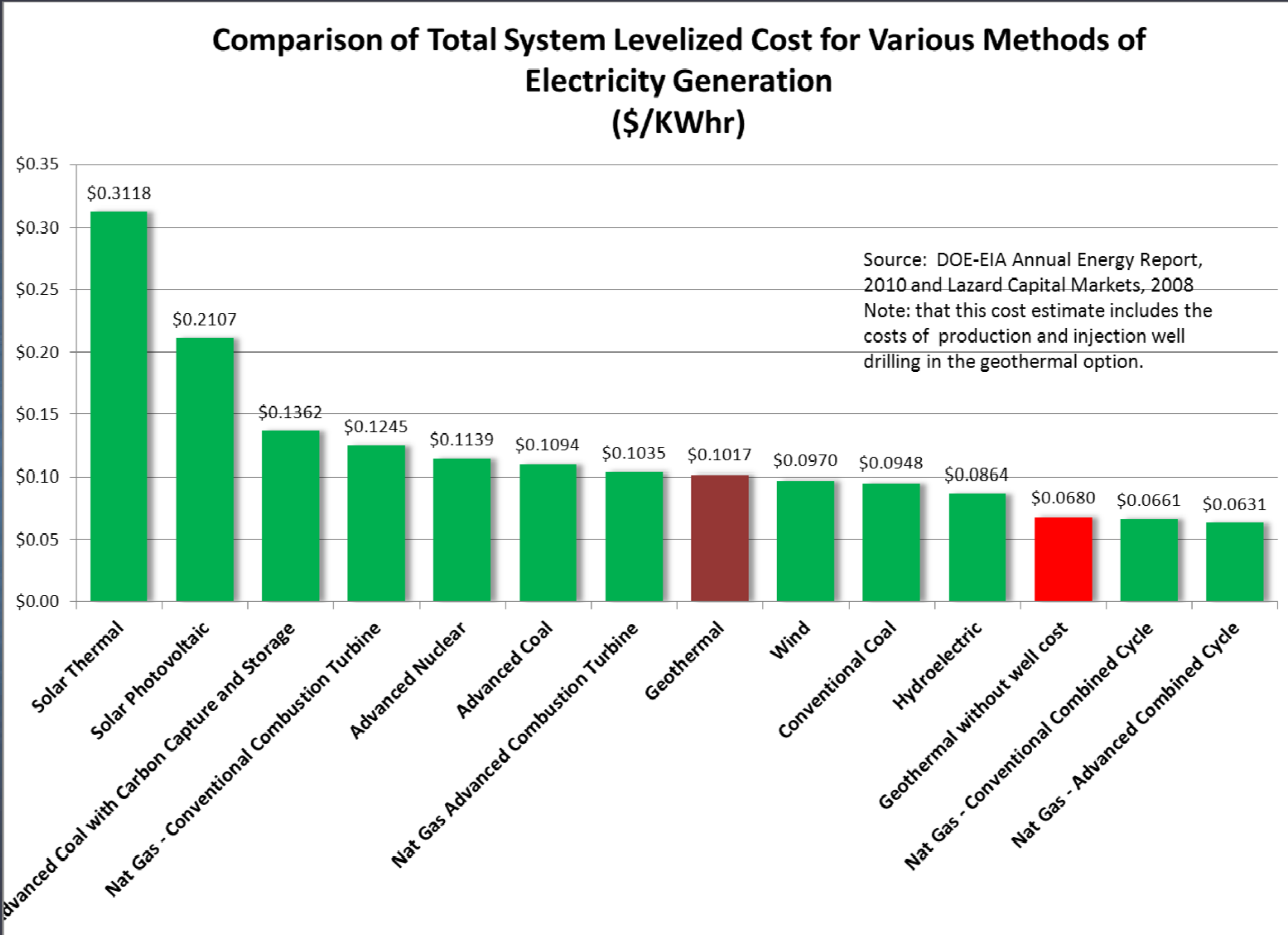



Reservoir Volume
(assume 30% developable)
Calculation of Extractable Heat Qr=V*ρc * (ΔT) where ρc= (Øρwcw+(1-Ø)ρrcr)
Thermal to Electrical Energy conversion efficiency (est. 10%)
Distribution over productive life time (÷ 20 yrs)

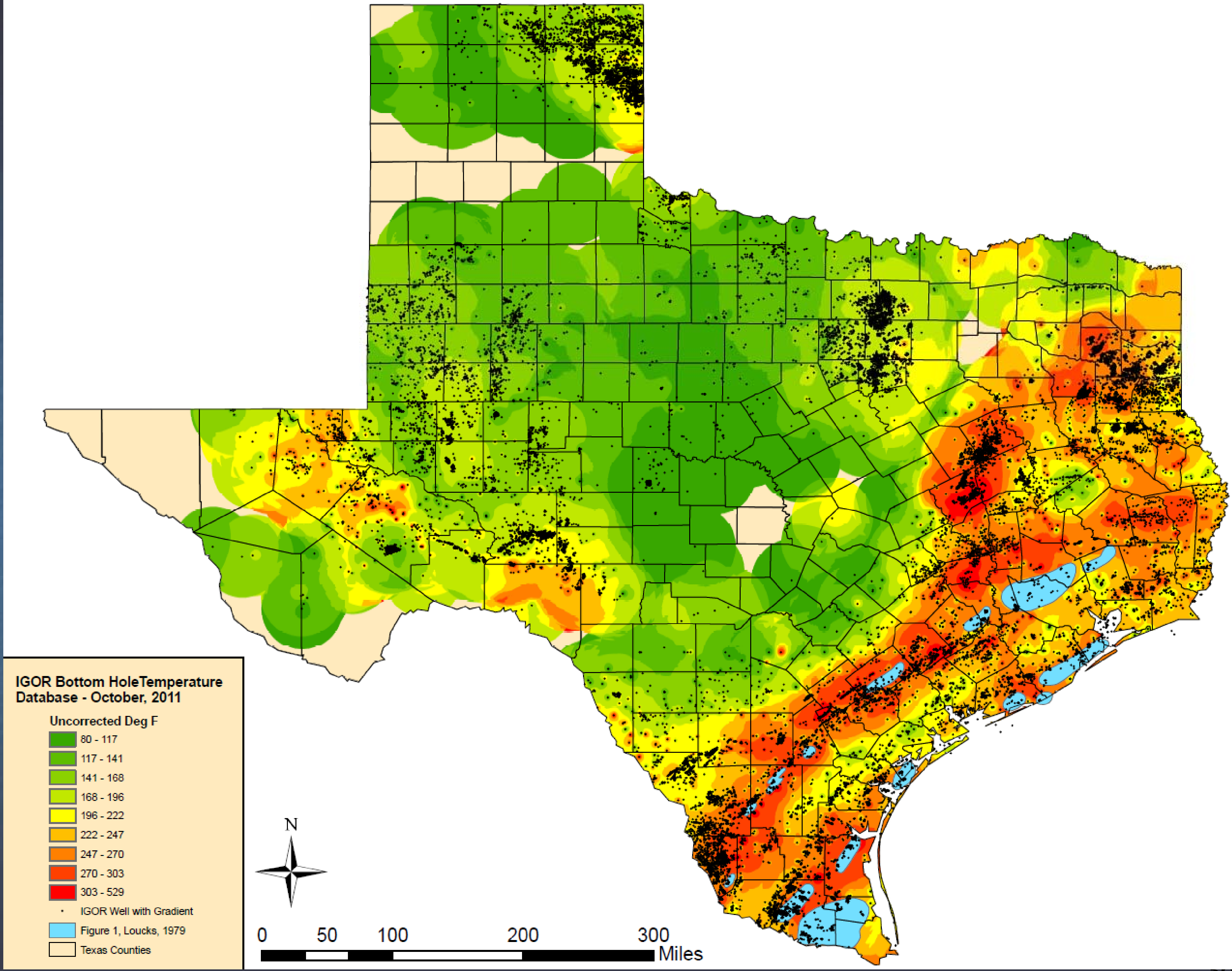
Gas Shale Basin	Barnet	Fayetteville	Haynesville	Marcellus	Woodford
Estimated Basin Area, Square Miles	5,000	9,000	9,000	95,000	11,000
Depth Range, low ft.	6,500	1,000	10,500	4,000	6,000
Depth Range, High, ft	8,500	7,000	13,500	8,500	11,000
Thickness, Range low, ft	100	20	200	50	120
Thickness, Range, High, ft.	600	200	300	200	220
Total Porosity	0.04	0.05	0.06	0.10	0.06
Well Spacing, Acres, low	60	80	40	40	640
Well Spacing, Acres, High	160	160	560	160	640
Reservoir Volume, low, cubic meters	3.95E+11	1.42E+11	1.42E+12	3.75E+12	1.04E+12
Reservoir Volume, high, cubic meters	2.37E+12	1.42E+12	2.13E+12	1.50E+13	1.91E+12
Range, Formation Temperature, ^{0}F	175-225	100-200	275-350	100-200	150-275
Delta T (from high T)	50	50	50	50	50
heat in place Joules	1.43E+20	3.87E+19	1.12E+21	9.69E+20	5.51E+20
kilowatt hours (tot)	3.99E+13	1.08E+13	3.11E+14	2.69E+14	1.53E+14
Megawatt hours (tot)	3.99E+10	1.08E+10	3.11E+11	2.69E+11	1.53E+11
mw per yr over 20 yr	227,516	61,399	1,775,036	1,536,273	873,641
Deliverable power MW	**2,275**	**614**	**17,750**	**15,363**	**8,736**

The Transformation of Tight Shale Gas Reservoirs to Geothermal Energy Production

- The Haynesville has a basin area of 9,000 square miles
- Average depth is between 10,500 and 13,500
- Average thickness is 250 feet, feet
- With bottom hole temperatures above 250 ^{0}F
- The potentially extractable thermal energy in this formation alone is 17,000+ Megawatts! (2.4 x 10^9 BOE)



Bureau of Economic Geology



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IGOR Well with Gradient
Figure 1, Loucks, 1979
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N
0
50
100
200
300
Miles

It is worth emphasizing that, even if a fraction of this energy is recoverable, then there is no reason to expect any energy shortage for the next several centuries! This is 1.56 Trillion barrels of oil equivalent

Texas Gulf Coast High Potential Geothermal Fairways	Area Sq km	Total Energy (Joules)	Total Energy (BBLs of oil equivalent)	TOT ENERGY Equivalent Installed Capacity in MW for 30 yrs (MWhrs/(hrs per year*30*90%))	TOT THERMAL ENG Equivalent Installed Capacity in MW (MWhrs/(hrs per year*360*90%))	TOT METHANE ENG Equivalent Installed Capacity in MW (MWhrs/(hrs per year*30*90%))	Total Thermal Energy (Joules)	Total Methane Energy (MMSCF)	Total Methane Energy (Joules)
Zapata	239	1.56E+20	2.56E+10	1.83E+05	1.22E+05	6.10E+04	1.04E+20	4.72E+07	5.19E+19
Duval	1,425	8.63E+20	1.42E+11	1.01E+06	6.88E+05	3.26E+05	5.86E+20	2.52E+08	2.77E+20
Live Oak	206	1.42E+20	2.32E+10	1.66E+05	1.20E+05	4.66E+04	1.02E+20	3.61E+07	3.97E+19
DeWitt	633	3.15E+20	5.17E+10	3.70E+05	2.45E+05	1.25E+05	2.09E+20	9.65E+07	1.06E+20
Colorado	819	4.49E+20	7.36E+10	5.27E+05	3.71E+05	1.56E+05	3.16E+20	1.21E+08	1.33E+20
Harris	4,486	3.43E+21	5.62E+11	4.03E+06	2.61E+06	1.42E+06	2.22E+21	1.10E+09	1.21E+21
Wilcox (tot)	**7,808**	**5.36E+21**	**8.78E+11**	6.29E+06	4.15E+06	2.14E+06	**3.54E+21**	**1.65E+09**	**1.82E+21**
Hidalgo	2,968	2.46E+21	4.04E+11	2.89E+06	2.27E+06	6.27E+05	1.93E+21	4.85E+08	5.34E+20
Corpus Christi	663	3.16E+20	5.18E+10	3.71E+05	2.92E+05	7.88E+04	2.49E+20	6.10E+07	6.71E+19
Matagorda	517	2.19E+20	3.59E+10	2.57E+05	1.90E+05	6.70E+04	1.62E+20	5.19E+07	5.71E+19
Brazoria	1,650	9.26E+20	1.52E+11	1.09E+06	8.66E+05	2.22E+05	7.37E+20	1.72E+08	1.89E+20
Armstrong	194	2.08E+20	3.41E+10	2.44E+05	1.77E+05	6.70E+04	1.51E+20	5.19E+07	5.71E+19
Frio (tot)	**5,992**	**4.13E+21**	**6.78E+11**	4.85E+06	3.79E+06	1.06E+06	**3.23E+21**	**8.22E+08**	**9.04E+20**
Total Frio + Wilcox	**13,800**	**9.49E+21**	**1.56E+12**	1.11E+07	7.95E+06	3.20E+06	**6.77E+21**	**2.47E+09**	**2.72E+21**

Notes:

1 std cubic foot of natural gas contains 1.1 x 10^6 joules

1 std barrel of crude oil contains 6.1 x 10^9 joules

The AAPG defines a "Giant" oil field as one that has at least 500 million barrels of oil. Using this definition, the Wilcox and Frio Fairways have the equivalent of 3,110 "Giant" oil fields remaining in extractable energy

Note on Scientific Notation. 1,000,000 is $1X10^6$ and is represented in this table as E+6 (Millions,) E+9 is Billions, E+12 is Trillions. Using as an example the bottom number of column 3, the total energy in barrels of oil equivalent in the Frio and Wilcox Formation is 1.56 Trillion barrels.

Ref: Esposito, A. and C. Augustine. Geopressured Geothermal Resource and Recoverable Energy Estimate for the Wilcox and Frio Formations, Texas. GRC Transactions, vol. 35, October, 2011.

- Thank you

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